

# M&V Value Tool Alpha Version Specifications

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**PREFACE ..... 3**

**ACKNOWLEDGEMENTS..... 4**

**1. INTRODUCTION..... 5**

    1.1. INTENDED USERS ..... 5

    1.2. ORGANIZATION OF DOCUMENT ..... 5

    1.3. TERMINOLOGY ..... 5

**2. GOALS..... 7**

    2.1. PERFORM SAVINGS AND SAVINGS UNCERTAINTY ANALYSIS ..... 7

    2.2. ASSIST WITH ASHRAE 14P RETROFIT ISOLATION APPROACH ..... 7

    2.3. ESTIMATE M&V COSTS..... 7

    2.4. AID IN PROJECT PLANNING ..... 7

**3. BACKGROUND..... 8**

    3.1. M&V VALUE TOOL GENERAL DESCRIPTION ..... 9

        3.1.1. *Energy Conservation Measures* ..... 10

        3.1.2. *Energy Savings*..... 11

        3.1.3. *Savings Uncertainty*..... 13

        3.1.4. *Sources of Uncertainty* ..... 14

        3.1.5. *M&V Costs*..... 17

        3.1.6. *M&V Cost-Effectiveness* ..... 17

        3.1.7. *Tool Use and Reporting*..... 17

        3.1.8. *Tool Modules* ..... 18

**4. FUNCTIONAL SPECIFICATIONS ..... 19**

    4.1. OVERVIEW ..... 19

    4.2. HARDWARE/SOFTWARE SPECIFICATIONS..... 19

        4.2.1. *Hardware Considerations*..... 19

        4.2.2. *Software Considerations*..... 19

        4.2.3. *Graphical User Interface*..... 20

    4.3. LOGICAL STRUCTURE ..... 21

        4.3.1. *Organization* ..... 21

        4.3.2. *Project Level* ..... 23

        4.3.3. *ECM Level* ..... 25

        4.3.4. *M&V Method Level* ..... 31

        4.3.5. *Data Collection Method Level* ..... 36

        4.3.6. *Data Collection Equipment Level*..... 41

**REFERENCES..... 52**

**APPENDIX A. EQUATION FILTER TABLES ..... 53**

**APPENDIX B. EQUIPMENT TABLE ..... 63**

**APPENDIX C. TOOL FUNCTIONAL TESTING..... 67**

    TESTING CRITERIA FOR LIGHTING ..... 68

    TESTING CRITERIA FOR A FAN MOTOR..... 75

## **Preface**

The purpose of this document is to present draft specifications of the alpha version of the M&V Value Tool. The document should provide sufficient documentation for industry participants to understand the Tool's scope and utility and for software developers to develop this Tool.

The format was developed and refined through specification of the existing M&V Value Tool Prototype. The prototype specifications and format were reviewed by a small group of industry experts and software developers. Their comments have helped improve this document.

The specifications provided here are functional specifications, as opposed to design specifications. Those wishing to develop software in compliance with these functional specifications will first need to develop design specifications.

We seek peer review of these specifications. Reviewers should be able to understand the Tool's data, organization, and functions using the format provided. In particular, we seek review of the following:

- The methods of savings calculation
- Identification, calculation and propagation of uncertainty in savings estimates
- Project and M&V cost treatment and tracking
- Comments on the proposed use of benefit-to-cost ratios to select appropriate M&V plans

We also seek reviewers' comments on the clarity of the Tool's description.

Tool test results are included, so that Tool developers may check their software with specified inputs and outputs.

We will use the feedback to improve the specification format, Tool description, and calculation procedures.

The goal of this project is to release these specifications to the public, specifically to the professional community involved with energy conservation projects, in order that they may have clear guidelines to develop software applications.

## **Acknowledgements**

Funding for this work was provided by Pacific Gas and Electric Company, Steve Blanc, Project Manager. Significant assistance and insight in developing these specifications was provided by Ken Gillespie, also of PG&E. A small review committee provided helpful insight: John Cowan of Energy Services Consortium, Rich Fromberg of PG&E, and Eric Walstadt, an independent software developer. Their contributions and encouragement are gratefully acknowledged.

We will continue to seek peer review and feedback from members of the ESCO community, ASHRAE 14P committee members, performance contract program managers at utilities and the federal government, and software developers. Their contributions and insight will be invaluable.

## 1. Introduction

This document contains the specifications for the alpha version of the Measurement and Verification (M&V) Value Tool (the “Tool”). A prototype of this Tool was developed for PG&E under the California Energy Commission’s 1998 Public Interest Energy Research (PIER) transition program.

### 1.1. *Intended Users*

The intended users of this Tool include those familiar with developing and implementing energy efficiency projects: facility technical staff, energy service companies (ESCOs), researchers, utility program managers, and project financial planners.

### 1.2. *Organization of Document*

This document consists of introductory sections that describe the Tool’s scope as well as its usefulness and sections containing the Tool’s *functional specifications*. In general terms, the functional specifications describe hardware and software considerations, variables, organizational structure, data requirements, and preferred input/output requirements. In comparison, *design specifications* describe how the Tool will be implemented—the hardware and software to be used, specific detail about the functional algorithms implemented, the formats of graphical user interfaces, and so on.

This document provides extensive and detailed functional specifications. It is intended to provide enough detail for those who wish to develop their own design specifications, software applications, and users manuals.

### 1.3. *Terminology*

This section is used to provide definition of common terms and acronyms used throughout this document.

ECM – energy conservation measure

Equipment – refers to energy end-use devices or systems, such as chillers, motors, lighting fixtures, and so on, or to measurement instruments, such as sensors and data loggers.

M&V – Measurement and Verification

M&V Plan – A description of the specific procedures and analysis steps taken to measure and verify an ECM’s savings. Synonymous with M&V scenario

M&V Scenario – Synonymous with M&V plan.

M&V Cost – The annual labor and materials costs associated with implementing the M&V plan. This cost includes specifying and procuring measurement instruments, metering and monitoring activities, data analysis and reporting.

**M&V Method** – An M&V method for quantifying energy savings for the specific end-use (as opposed to a whole-building approach).

**Stipulate** – As opposed to quantifying a parameter value with actual measurements, stipulating a parameter is assigning it a value based on some prior knowledge, assumption, or inference from other available data. Because there are no measurements involved, the Tool assumes a 50% uncertainty for stipulated values.

## 2. Goals

The main goals of the M&V Value Tool are to:

- Perform savings and savings uncertainty analysis
- Assist in implementing the ASHRAE 14P retrofit isolation method
- Estimate M&V costs
- Aid in project planning

These goals are discussed in the following subsections.

### 2.1. **Perform Savings and Savings Uncertainty Analysis**

Rarely are energy savings expressed with uncertainty and confidence limits. Indeed, it is practically impossible to do so for many energy efficiency projects. However, there are projects for which one can forecast savings and uncertainty; these generally involve whole buildings and pieces of equipment that can be isolated or treated independently from their surroundings. This Tool is designed to estimate savings and savings uncertainty for isolated equipment. Whole-building savings and uncertainty analysis is discussed elsewhere in the literature (Reddy, Kissok and Ruch, 1998, Katipamula, Reddy and Claridge, 1995, and ASHRAE 14P ). The Tool will enable energy efficiency service providers to inform owners and financial backers about some of the important risks associated with a project's savings.

### 2.2. **Assist with ASHRAE 14P Retrofit Isolation Approach**

The American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., (ASHRAE) has released *ASHRAE Guideline 14P: Measurement of Energy and Demand Savings, First Public Review Draft, 2000*. The guideline describes three approaches to M&V of energy savings, one of which is the retrofit isolation approach. Compliance with the guideline means that energy savings determined through M&V procedures must be stated with an accompanying statement of uncertainty and confidence level. A goal of the Tool is to provide a means to determine the uncertainty and confidence level associated with the estimated energy savings.

### 2.3. **Estimate M&V Costs**

The Tool should help project planners define the specific M&V activities needed to quantify baseline and post-installation variables, perform analysis, and provide reports as required by a performance contract or other performance-based activity. The Tool should enable users to associate costs with the activities that make up an M&V plan.

### 2.4. **Aid in Project Planning**

The Tool will perform a cost/benefit analysis that enables the comparison of one M&V scenario with other scenarios. With all the information available to the user, the Tool will facilitate investigation of alternate M&V scenarios and help identify the largest sources of uncertainty. The goal is to help planners allocate available resources to the areas where they are most needed.

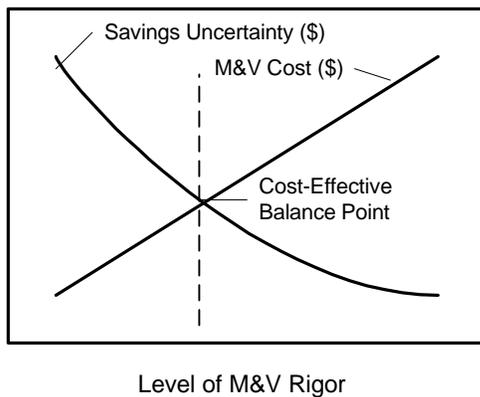
### 3. Background

The functional specifications that follow describe the requirements of a software tool (hereinafter referred to as the “M&V Value Tool” or simply “Tool”) to assist project planners in developing cost-effective M&V plans. This section's narrative provides a description of the Tool's structure for both energy professionals and software developers to understand its scope and purpose as well as the technical perspective described later in the specifications.

A necessary but seldom performed exercise in the measurement and verification of energy savings associated with energy efficiency projects is assessing the accuracy of the predicted savings. In performance contracts, payments are based on the results of M&V, and the parties need to be reasonably certain that the payments are appropriate.

Ideally, the savings should be determined as accurately as possible. This may be accomplished by using accurate measurement equipment and collecting extensive data sets. However, more rigorous M&V plans are costly, and a point is reached beyond which increasing the rigor of M&V is no longer cost-effective. Figure 1 below demonstrates that more rigorous, and thus more costly, M&V activities reduce savings uncertainty, but that a point is reached beyond which the incremental reductions in savings uncertainty are not justified by the M&V costs.

**Figure 1. Comparison of savings uncertainty and M&V costs.**



Because M&V activities can be costly, the value of information they provide should play an integral role in their design. An M&V plan may be considered cost effective if (1) its costs are a small fraction of the energy cost savings and (2) its savings estimate is within a reasonable uncertainty level.

Various M&V guidelines cite rules-of-thumb cost-to-savings fractions of 5 to 15%, thereby providing some commonsensical guidance for the first criteria. In general, guidance on the second criteria has not been addressed in the literature until recently. Of the various M&V guidelines, only ASHRAE 14P requires that a statement of savings uncertainty be included in M&V plans. The requirement is that the level of uncertainty be less than 50% (at the 68% confidence interval) for the reporting period.

The Tool develops estimates of savings uncertainty through engineering and statistical methods. In general, energy savings are calculated from selected equations. The uncertainty in the

equations' variables are combined to obtain estimates of the overall savings uncertainty. The methods used to propagate uncertainty are generally known in the engineering and statistical literature (ASHRAE Guideline 2-1986 (RA 96), ANSI/ASME Standard PTC 19.1-1985). Some recent developments in estimating uncertainty that are specific to energy savings projects are also included in the Tool (Brandemuehl, et. al., ASHRAE RP827, 1996, and Reddy, Haberl, and Elleson, 1999).

Estimating the savings uncertainty is part of assessing a project's risks. It is important to assess a project's risks when considering an energy savings measure. While the magnitude of savings uncertainty has implications of a project's risks, it is only one of many factors that should be considered. Other risk factors of an energy savings project, include financing (interest rate fluctuations, energy costs) and the installation (schedule, crew management, delays, material availability). The Tool does not address these issues; other treatises are available on methods for assessing a project's risks (Marshall, 1998).

Calculating energy savings and M&V plan costs are necessary activities commonly practiced in the industry. However, practitioners are usually loath to perform the necessary uncertainty analysis in order to assess their M&V plan's accuracy. There are numerous sources of uncertainty; identifying and treating them properly in energy savings projects is an engineering practice still in its infancy. However, knowledge of the savings uncertainty is a crucial element in making meaningful comparisons of alternative M&V plans for the same project.

A computer application to overcome these obstacles should help project planners early in the development stage to quickly develop numerous M&V scenarios for their projects and enable them to make meaningful comparisons of each scenario. In order to accomplish these tasks, the application should help users develop specific M&V activities as well as estimate energy savings, savings uncertainty, and M&V costs.

### **3.1. M&V Value Tool General Description**

The Tool's scope includes common energy conservation measures (ECMs) that can be isolated and examined independently from other influences in the facility. It may be used to develop savings uncertainty estimates for IPMVP Option A and Option B or ASHRAE 14P's retrofit isolation method, all of which include M&V methods for individual ECMs. (The IPMVP Options C and D, and other ASHRAE 14P methods, are whole-building, main-meter, and computer simulation methods.)

The Tool enables users to select an approach to calculate savings, identify variables, select data collection methods, and so on in order to build an M&V scenario. The specifications describe how the Tool tracks user selections and data inputs to estimate the measure's energy savings and savings uncertainty and the costs associated with the equipment and activities selected.

Other important functions of the Tool are described: establishing cost-effectiveness metrics that enable comparisons of different M&V scenarios, specific reporting requirements that describe the savings, uncertainty and cost of the selected M&V plan, documentation of the assumptions used to develop it, and Tool modules that allow users to expand and customize the Tool's database of data collection equipment, energy efficiency measures, and M&V methods.

Following are general descriptions of the important elements of the Tool. They are provided to clarify the methods described in the functional specifications that follow.

### 3.1.1. Energy Conservation Measures

There are a huge number of projects that save energy in buildings and facilities. To be useful, the Tool should encompass as many energy conservation measures as possible. The Tool's framework is based on ASHRAE 14P's retrofit isolation method, and characterizes ECMs by identifying the ECM's category, the baseline equipment load and operation schedule characteristics, and the impact of the retrofit on the load or schedule. To characterize an ECM, the user must:

- (1) Establish the ECM category. The Tool includes ECM categories for lighting, pump and fan motor, chiller, boiler, furnace and package unit air-conditioning projects.
- (2) Select baseline equipment load class. The baselineline equipment may be characterized as constant load (CL) or variable load (VL). While ASHRAE 14P requires that a load may be classified as constant only when it varies by 5% or less, the Tool allows the user to specify this variation.
- (3) Select the baseline equipment schedule class. The baseline equipment may be characterized as a timed schedule (TS) or a variable schedule (VS). Equipment running on a timed schedule have constant and predictable operation hours throughout the year. This is not true of variable schedule operation – in which the operation hours may vary randomly or depend on an external driving force.
- (4) Identify the change induced by the retrofit. The Tool includes six possible changes that the proposed retrofit may induce:
  - (a) A load change where the magnitude of the load may be reduced as a result of the retrofit, occurs without changing the load class.
  - (b) A schedule change where the number of operating hours are reduced as a result of the retrofit, without changing the schedule class.
  - (c) A combined load and schedule change where the load and operating hours are reduced as a result of the retrofit, without changing the load and schedule class.
  - (d) A change of a constant load to a variable load.
  - (e) A change of a timed schedule to a variable schedule.
  - (f) A change of both a constant load to a variable load and a timed schedule to a variable schedule.

While these categories will not completely capture all retrofit projects that may be analyzed under these approaches (i.e., ASHRAE retrofit isolation, IPMVP Options A and B), they include most

project types and the projects seen most frequently in California utility programs.<sup>1</sup> The user selects the ECM category, load class, schedule class, and type of retrofit change, and the Tool provides a list of possible equations that may be used to calculate energy savings.

### 3.1.2. Energy Savings

The fundamental process to calculate energy savings is to identify the energy savings equation and to characterize the variables in the equation. The user should have data ready to define the variable values. The data should be from a preliminary audit of the facility. Once all variable values have been provided, the Tool calculates the savings.

The amount of energy savings is determined from the difference between baseline and post-installation energy consumption. In turn, the energy consumption of a device can be determined by the product of (1) factors that make up the equipment load and (2) the usage of the equipment, usually measured in hours. Examples of factors that make up the equipment's load include lighting fixture demand, chiller efficiency, and motor demand. Examples of equipment usage include lighting operation hours and the load frequency distribution of a variable speed air-handling fan.

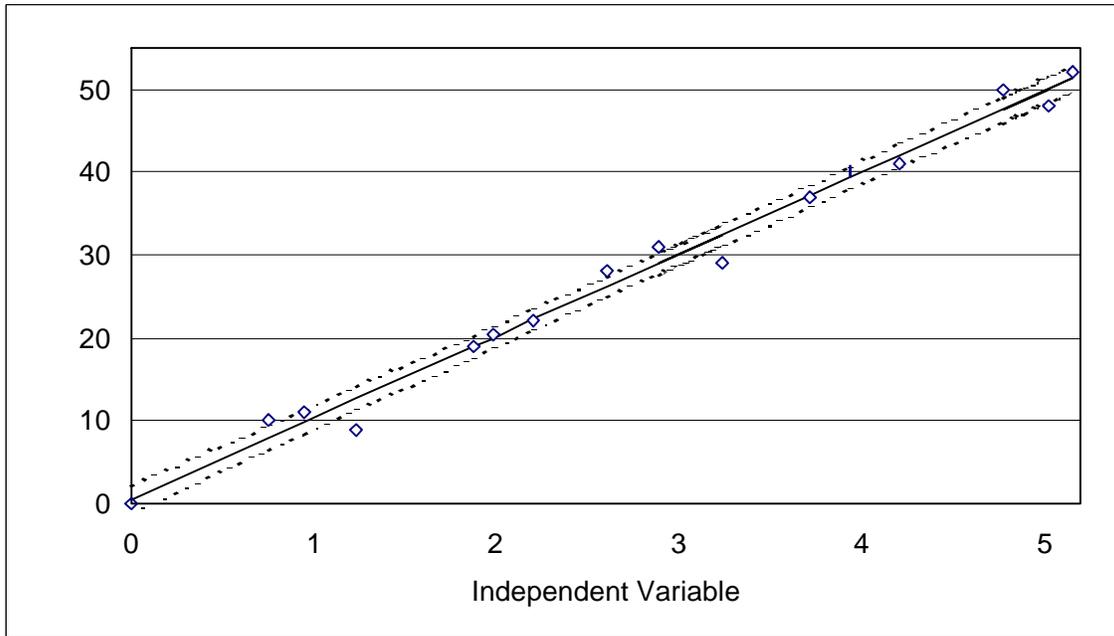
Appendix A contains four tables of energy savings equations, for each combination of load class and schedule class. The load and schedule classes were defined previously. The four tables correspond to the following four combinations of load and schedule class: CL, TS; CL, VS; VL, TS; and VL, VS. Each equation represents a different means of determining energy savings. A short list of possible equations is identified by selecting the ECM category, load and schedule class, and retrofit change.

Variable load and variable schedule equipment are treated as a series of discrete operation levels of the equipment. Variable load or schedule equipment are represented in the equations by summations over an index. The summations may be for different load levels, or different operation schedules. For variable load equipment, the Tool assumes that a relationship between the dependent variable (kW, Eff,  $Q_L$ , and Btuh) and one or more independent variables (pump water flow rate, fan airflow rate, motor speed, boiler load, and so on) may be developed by a series of measurements on the equipment, as demonstrated in Figure 2. For variable schedule equipment, the Tool assumes that a load frequency distribution of binned hours of operation at various load levels may be developed, as demonstrated in Figure 3.

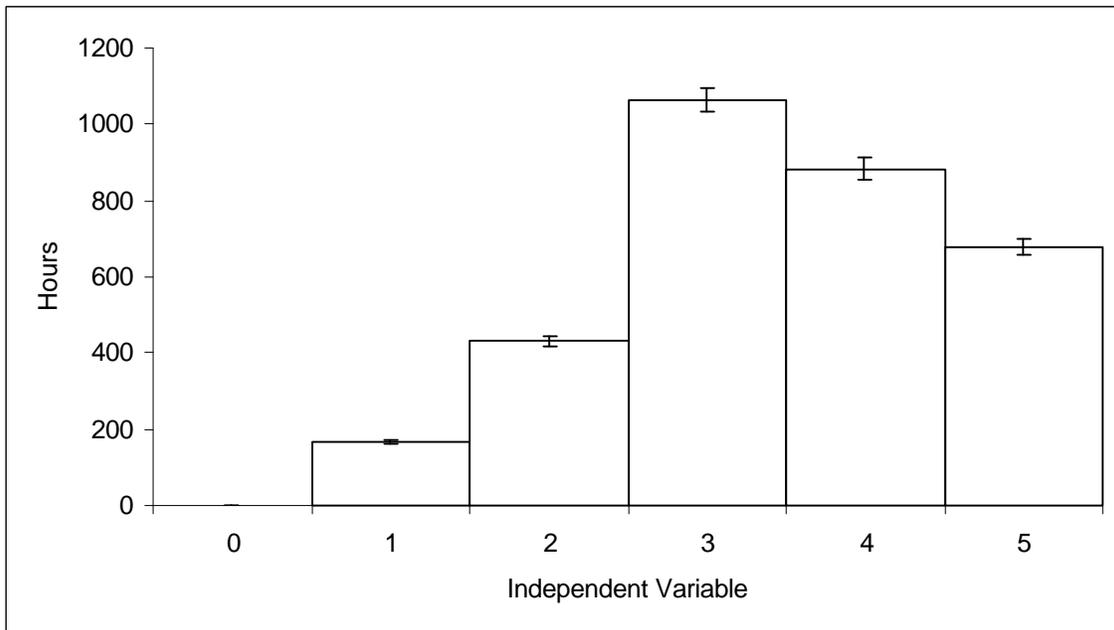
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<sup>1</sup> The programs referred to are Standard Performance Contract Programs (SPC). For information, visit the web sites at <http://www.pge.com/spc> and <http://www.scespc.com>.

**Figure 2. Graphical representation of an example relationship between a load variable and an independent variable. Note: dotted lines indicate 68% confidence interval of model prediction.**



**Figure 3. Example load frequency distribution, with error bars shown.**



The approach of first defining the equations and then identifying the variables, allows a more complete characterization of the savings calculation method. The equation depends on the equipment characteristics and impact of the retrofit. The variables are characterized not only by their type and value, but also by their uncertainty. The utility of this approach is in capturing the

diffuse sources of uncertainty and propagating them through the equations to calculate the measure's overall energy savings uncertainty.

### 3.1.3. Savings Uncertainty

Energy savings may never be directly measured because baseline and post-installation data cannot be collected at the same time. This implies that either the energy behavior of the baseline or the post-installation equipment must be modeled. The standard practice is to model the energy behavior of the baseline equipment. Techniques for doing so are discussed in ASHRAE 14P.

Savings uncertainty is developed from identifying and quantifying each source of uncertainty in the terms in the savings equation and propagating them through the mathematical operations of the equation. The sources of uncertainty are identified when the user selects the method of data collection. There are six data collection methods in the Tool:

- (1) Stipulation. The variable value is obtained from knowledge of the equipment's load or schedule and can be estimated with reasonable certainty. The Tool allows the user to estimate the uncertainty associated with the value or assigns 50% uncertainty as a default. The stipulation method is allowed for constant load equipment, timed schedule, or variable schedule equipment.
- (2) Single Spot Measurement. The variable value is obtained from a single spot measurement on constant load equipment. The uncertainty of the value is obtained from the measurement instrument precision and bias uncertainty. This method does not apply to variable loads or schedule variables.
- (3) Averaged Spot Measurements. The variable value is obtained from the average of a number of measurements on the equipment, using the same measurement instrument. The uncertainty is the uncertainty in the mean of those measurements. This method also does not apply to schedule variables.
- (4) Multiple Spot Measurements. A series of measurements of dependent and independent variables are made as the equipment is manually forced through its entire range of operation. The dependent variables are load variables such as kilowatts, equipment efficiency, or natural gas burn rate. Examples of independent variables are air or water flow rates, chilled or hot water temperatures, and so on; their identity depends on the equipment and the proposed regression relationship. The measurements on the dependent and independent variables are used to develop a relationship between the load variable and an independent variable, usually with statistical regression techniques. The uncertainty in the dependent variable is a combination of the model precision and measurement instrument precision and bias uncertainty. Model bias uncertainty is assumed to be negligible because the measurement tests are assumed to cover the entire range of data.
- (5) Short-term Monitoring. Measurements of load or schedule variables, and selected independent variables are made at constant intervals over a short-term period. For variable load equipment, the period length must be long enough to capture the entire range of equipment operation. When used to obtain schedule information, the period must be long

enough to quantify the timed schedule operation or quantify the bins of the load frequency distribution. For variable load equipment, the uncertainty is developed as described above for multiple spot measurements, with the additional requirement that the model bias uncertainty must be estimated for cases where the monitoring did not capture the entire range of operation. When using this method to collect schedule information, the uncertainty is obtained from the monitoring instrument, such as a time-of-use meter or a meter that records data at specified intervals. For variable schedule cases, there is also uncertainty associated with extrapolating the short-term data to the full year.

- (6) Continuous Monitoring. Used primarily for monitoring energy consumption (kWh or therms) or operation hours, measurements of load or schedule variables are made at constant intervals continuously. Uncertainty is obtained from the measurement instrument, summed over the total number of measurements recorded.

All uncertainties are specified at a common confidence interval of 68% in the Tool. The data collection methods are shown for each load and schedule class in Table 1.

**Table 1. Variable Data Sources.**

Load and Schedule Class	Data Collection Methods
CL	Stipulate
	Single Spot Measurement
	Averaged Spot Measurements
VL	Multiple Spot Measurement
	Short-term monitoring
	Continuous monitoring
TS	Stipulate
	Short-term monitoring
VS	Stipulate
	Short-term monitoring
	Continuous monitoring

The method for calculating uncertainty is based on common error-propagation techniques. For example, the error in a quantity that is the sum of two other quantities is determined from the square root of the sum of squares of the absolute uncertainties of the two other quantities. Error propagation routines for addition and subtraction, multiplication and division, and for raising one quantity to the power of another quantity are included in the Tool. The Tool uses a character-recognition algorithm on the savings equation to determine the proper sequence of error propagation. It then combines the variable values and uncertainties in the specified sequence to determine the energy savings uncertainty.

### 3.1.4. Sources of Uncertainty

Uncertainty in savings estimates arises from numerous sources that originate from the data collection method. A representative sample of equipment may be measured instead of the entire

population of equipment. Imperfect relationships between independent variables and dependent variables may be used.

Error is the difference between the estimated value and the true value of a parameter. Because the true value is unknown, the true error cannot be known absolutely. However, the error limits may be estimated. These limits define an interval around the parameter estimate, within which the true value is contained. Because the limits are estimated, proper statements of uncertainty include a definition of the confidence level at which the interval is known.

The sources of measurement uncertainty that are relevant to calculation of energy savings fall into the following categories:

- Measurement precision and bias
- Model precision
- Model bias
- Sampling

Measurement uncertainty is the combination of calibration and instrumentation errors, data acquisition errors, and data reduction errors. These errors may lead to a systematic or bias error and a random error, also known as precision or “white noise” error. Random error is the portion of the total measurement error that varies in repeated measurements of the true value. While random errors have equal probability of under- or over-predicting the true value, bias or systematic errors consistently either over- or under-predict it. To clarify these terms, in general, a measurement with low bias error has good accuracy, while a measurement with low random errors has good precision.

The uncertainty due to random error may be estimated by inspecting the measurement scatter. Bias error is estimated based on knowledge of the device or system under measurement. Each case is different so that there are no standard algorithms to estimate bias errors. To reduce the impact of bias errors in data analysis, the best practice is to reduce them before making measurements or analyzing the data (e.g., by calibrating the instruments). Another source of bias error is the error developed from improper placement of sensors or improper measurement techniques. These errors can be mitigated by following proper test procedures.

An extensive source of equipment testing procedures are found in ASHRAE 14P, and ASHRAE 827-RP. The procedures contain testing protocols for most of the end-use equipment covered encountered in the field. The procedures also provide a means for identifying and estimating the uncertainties required to use this Tool.

The Tool includes a table that contains names of different measurement instruments with their manufacturer’s specified uncertainty. Manufacturers of measurement instruments rarely state the confidence level of their instrument’s uncertainty. The Tool adopts the convention from ASHRAE Guideline 2-1986 (RA-96) and ASME, 1998 to assign 95% confidence level to instrument manufacturer specifications of uncertainty.

Model precision uncertainty arises from calculating the dependent variable through modeling of independent variables, such as in a regression model (Reddy, Haberl, and Elleson, 1999, Brandemuehl, et. al., 1996). When a regression model is fit to data, an imperfect relationship results. The coefficients have some inherent error since any regression model with an  $R^2 < 1$  is incapable of explaining the entire variation present in the regressor variable. This is known as the model internal prediction uncertainty. Model specification errors are another type of model precision uncertainty, and these arise when the functional form of the regressor model does not adequately approximate the true behavior of the response variable. Engineering insight helps reduce this type of error.

When a relationship between variables is needed as part of an M&V scenario, the Tool queries the user as to how well that relationship will be characterized. A relationship is characterized by its model precision and bias uncertainties. The user is essentially being asked, “How well do you think you can make that relationship between the motor kW and air flow?” What the user specifies will be itemized in a report. The Tool will provide some guidance to the user on what values are reasonable. These examples are specific to the device under consideration.

Model bias uncertainty discussed in Reddy, 1999, is associated with extrapolating a model outside the range of data used to develop the model. An example is when a model developed from data collected over a short-term period is extrapolated to generate results for a longer time period, such as a year. This is relevant to energy savings calculations where results on an annual basis are generated from models developed with data obtained over a few weeks or months. Techniques for reducing these errors depend on the nature of the device behavior. In general, data should be collected over its expected range. For device behavior that varies with seasonal weather conditions, it may be appropriate to collect data in the spring or fall in order to capture a wide range of weather data.

In a similar fashion, the Tool will query the user to specify the model bias uncertainty. Depending on the range of data anticipated, and the user’s consideration of the range of data that will be used to develop the relationship, the user may specify different levels of model bias uncertainty.

When measurements are performed on a representative sample of equipment and used to estimate the population average, the uncertainty introduced by sampling is included. Sampling is adopted primarily to reduce monitoring costs. Sampling increases uncertainty—by how much depends on the data scatter and the sample size. Several assumptions are made in order to use sampling techniques. These include (1) the measurements of device parameters are independent of other measurements on other devices and (2) if a series of measurements were made on a single device parameter, the values would be normally distributed about a mean value. Both of these assumptions are an accepted practice in the industry.

The uncertainty introduced by sampling is the standard error of the measurements about the mean. The user selects a standard deviation and a precision and confidence level to specify the number of sample points to measure. The sampling uncertainty is combined with the measurement uncertainty to obtain the population uncertainty.

### 3.1.5. M&V Costs

The Tool must also produce cost estimates for each M&V scenario. The approach is high-level in that the user specifies the M&V activities and measurement equipment first, then estimates costs based on those activities. Some costs scale with the degree and rigor of the measurement activities. For example, a population of lighting fixture wattages may be measured or a sample may be measured. The measurement costs will scale with the number of measurements taken, their duration, and their frequency. The Tool will ask the user for analysis and reporting time estimates and for the hourly rates of the staff to perform the task. The Tool will identify fixed costs and the costs that scale with the scope of the project, such as labor and measurement equipment costs. Consistent with ASHRAE 14P, the Tool also allows measurement equipment to be amortized over a number of projects, so that one project does not pick up all the costs of the equipment.

This version of the Tool does not factor in the time value of money, which would essentially allow the M&V costs for the entire duration of the project to be included. The Tool calculates its cost-effectiveness metrics based on one year of annualized cost savings. Later versions of the Tool specifications may include costs over the lifetime of the measure.

### 3.1.6. M&V Cost-Effectiveness

The two metrics specified to assess an M&V plan's cost effectiveness are

- (1) The percentage of annual energy cost savings used for M&V
- (2) A ratio of the incremental benefit of one M&V plan compared to another over the incremental cost between the two plans

The definition of "benefit" used here is the reduction in savings uncertainty, expressed in terms of cost, in selecting one M&V plan over another. Note that this is not a tangible benefit in that reducing the uncertainty of an estimate does not put real dollars in the bank. However, it does provide an indication of the increase in confidence one has with the savings estimate.

The first criterion is used to assess how much of the cost savings are spent on M&V. Good practice and common sense, requires that this percentage be kept as low as possible. The second criterion is used to compare two different M&V plans. If the benefit-to-cost ratio is greater than one, the alternate plan is more cost-effective in comparison to the base case plan. However, that is all it says. Whether the M&V practitioner should select one M&V plan over another depends on each criteria, as well as on the goals of the project and parties involved. The Tool provides the information upon which to base these decisions.

### 3.1.7. Tool Use and Reporting

The Tool allows users to specify data collection methods, data collection equipment, and to estimate time required for measurements, analysis, and reporting. In making the selections, the user makes many "promises" or assumptions about how the plan will be carried out. For example, the user may choose to use a regression relationship between motor speed and kW consumption

for a variable-speed motor project. The accuracy of the regression relationship that the user promises to establish should be documented in the report. Similarly, the user may want to limit costs by limiting the number of hours an engineer may spend analyzing data. This is also documented by the Tool. The Tool specifications require that all promises and assumptions be noted and a report generated as documentation for users when procuring data collection equipment, setting time limits on analysis, inspections, reporting, and so on.

The specifications also describe reports that should be provided. These reports should enable the user to compare the multiple M&V scenarios and their cost-effectiveness metrics, in order to identify the appropriate M&V plan. A summary report that details the M&V plan is also necessary and can be used in contract documents.

### 3.1.8. Tool Modules

ECM Modules. The Tool specifications include a limited number of ECM modules. ECM modules are the ECM type, equations, variables, data collection methods, and data collection equipment that can be used to define M&V activities for the specific measure. The Tool focuses on some of the most-used ECMs, but is not comprehensive. The specifications describe requirements to develop software to add ECM modules to the Tool's databases. This enables users to expand the scope of the Tool for projects of particular interest to their business.

Equipment Table Module. The Tool's database of measurement and monitoring equipment is not comprehensive. However, commonly used instruments, such as wattage and watt-hour measurement instruments, are included. All measurement equipment is specified with a description, an uncertainty, a cost, and an amortization factor. The specifications describe requirements for software that is used to add and update equipment to the database.

## 4. Functional Specifications

### 4.1. Overview

This section describes the Tools requirements in terms of hardware and software, variables and data, its logical structure, and the necessary functions, calculations and relationships. It also describes reporting requirements. It defines the data requirements to provide the Tool with new ECM options, M&V methods and data collection equipment, etc.

### 4.2. Hardware/Software Specifications

Depending on the number of users and type of use expected, either stand-alone or client-server architectures may be used. Both of these have their advantages and disadvantages.

#### 4.2.1. Hardware Considerations

Some development platforms such as Microsoft Access, and Visual Basic require that a Windows based PC be used. Others like Java do not have this limitation and only require a runtime environment be installed. Therefore, the hardware considerations are somewhat dependant on the software platform selected for development. The following is a list of possible options:

- Windows based PC workstations
- Macintosh, Unix or other workstations.
- Internet server and any computer with a web browser.
- Any computer with a Java runtime environment.

#### 4.2.2. Software Considerations

The software development platform selected for the tool must provide a graphical user interface (GUI), efficient mathematical functions, and data storage capabilities. The tool functionality requires maintaining arrays of related module and project data. This can be accomplished through the use of a relational database, linked spreadsheets, flat files, or object oriented class hierarchies. With that in mind the following software platforms or combination thereof could be used:

- Java – Provides tools for building a GUI, mathematical functions, and JDBC for database connectivity. The object-oriented nature of this language also lends itself to the use of XML for data exchange between client and server applications. The primary advantage to using Java is its platform independence. However, some may argue that Java is less efficient than languages compiled for a particular platform primarily because of the overhead of the Java Virtual Machine (JVM).
- Visual Basic – This platform provides GUI building tools, mathematical functions, and ODBC for database connectivity. This language is optimized for the Windows platform, which is both its advantage and disadvantage. It does not support other operating systems.

- Microsoft Access – This is a good platform for developing small to medium scale database applications. It provides a nice GUI toolkit and the Visual Basic for Applications (VBA) programming language. This is a customized subset of Visual Basic specific for Microsoft's Office platform and provides both mathematical functions, and database connectivity. Although VBA is supported by all Office applications, including those on the Macintosh operating system, Microsoft Access is only available for Windows.
- Microsoft Excel – This spreadsheet application, which is part of the Microsoft Office platform, provides some limited GUI building tools. It is primarily used for raw data analysis, but shares many of the features of Access through its support of VBA like database connectivity and complex mathematical subroutines. Although links can be created between spreadsheets of data, Excel doesn't provide for a very good method of maintaining complex inter-related arrays of data.
- HTML and CGI – The Hyper Text Markup Language (HTML) is very useful for GUI building of client-server applications. The Common Gateway Interface (CGI) is a standard for developing server-based scripts that handle client requests in any number of programming languages including Perl, Python, and C. The client interface is developed as one or more hyper-linked web pages in HTML and one or more CGI scripts are written to perform all mathematical calculations, and data storage.
- Microsoft Active Server Page (ASP) – This is a meta-language embedded in HTML to provide the ability to interact with server-based functions. This was primarily developed for use with Microsoft's Internet Information Server (IIS), however, it has been ported to be used with the Apache web server on the Unix and Windows platforms.
- Oracle – This is an enterprise level database platform, which could be used as the database component in many of the above scenarios. Oracle is very good at maintaining large volumes of complex relational data, as well as performing some level of mathematical calculations. Oracle is available for most flavors of Unix and Windows servers.
- SQL Server – This is also another enterprise level database platform developed by Microsoft. This could also serve as the database component in many of the above scenarios, however it only runs on Windows servers. SQL server is well suited for use with Microsoft Active Server Page (ASP).

#### 4.2.3. Graphical User Interface

Some of the development platforms listed above include resources for designing a graphical user interface (GUI). Others provide only a data storage mechanism and must be used in conjunction with a GUI client. Regardless of the platform and interrelationship to the data storage and functional mechanisms the GUI must provide the following features:

- Input screens
- Data Validation before storage

- Ability to review and modify previously input data.
- Display reports for intermediate and final cost-benefit analysis

### **4.3. Logical Structure**

#### **4.3.1. Organization**

The Tool is organized into a structure that facilitates the development of an M&V plan. The development process is hierarchical and has several *levels*. At each level the user defines several *properties*. The levels and some of their properties are described below, and the relationship among the levels is shown in Figure 4.

Project Level: A project may consist of multiple ECMs, such as lighting, pumps, fans, chillers, boilers, furnaces, or package units (air conditioning only). This level of organization enables the definition of all ECMs under one project name. It also contains the aggregated energy savings estimates, savings uncertainty, and M&V costs.

ECM Level: Several properties of the ECM are defined at the ECM level: ECM category, load and schedule class, retrofit change, and usage group name and population. This level also contains the ECM-specific savings, savings uncertainty, M&V costs, and M&V plan cost-effectiveness metrics.

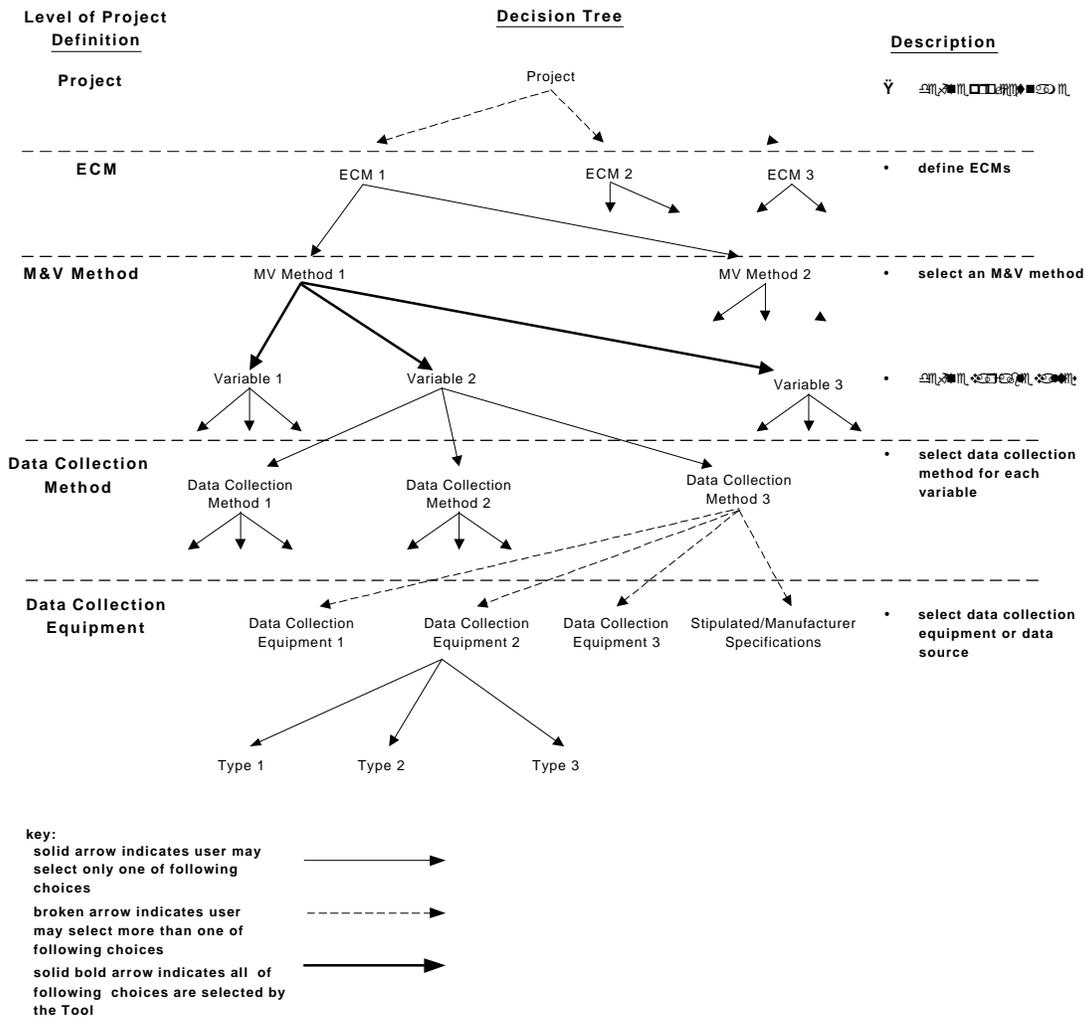
M&V Method Level: For each ECM, the user selects an M&V method; the method selected determines the specific savings equation. The equation defines the variables to be characterized. It also defines the method by which the energy savings will be calculated as well as the error propagation algorithms that will be needed to determine savings uncertainty. The choices of M&V methods available to the user are based on the inputs the user has made at the Project and ECM levels.

Data Collection Method Level: At this level, the user specifies values for the variables in the savings equation. Also specified are the methods for collecting data, such as stipulation, spot measurements, and short-term or continuous monitoring. For cases in which there are multiple devices in an ECM, such as a lighting project, the user defines the sampling strategy. The Tool calculates the total variable uncertainty and the costs of data collection equipment.

Data Collection Equipment Level: The user specifies the specific measurement instrument at this level. Selections made during this process will determine which uncertainties make up the variable uncertainty. The selections also identify the costs of measurement instrument. After the user has provided all information, the Tool may begin its analysis.

In the sections that follow, each level is described in detail. The descriptions include identification of information the user must provide, user selections from Tool-provided options, information that is passed among levels, calculations performed, and results produced.

**Figure 4. Tool level decision structure**



Sections 4.3.2 to 4.3.6 describe the properties in each of the Tool’s five levels. Each property is described in a separate paragraph, and a table summarizes all properties contained at that level.

### 4.3.2. Project Level

Table 2 lists all properties in the Project Level.

*Project Name.* The project name is provided by the user. Examples of project names include: ACME Towers, Port Authority, Wholesale Foods, and so on.

*ECM Names.* The name of each ECM included in the project. The Tool provides a list of names from which the user may choose (these names are defined by the user at the ECM level). The user may select multiple ECMs under one project name.

*Project Savings.* The sum of the savings generated by each ECM in the project. The value is calculated by the Tool. Savings may be energy or demand savings. Energy savings are annual values. The Tool calculates the project savings using the following equation:

$$SAV_{total} = SAV_{ECM1} + SAV_{ECM2} + SAV_{ECM3} + \text{and so on}$$

*Project Savings Uncertainty.* The project savings uncertainty is the combined savings uncertainties of each ECM in the project. It is determined by standard error propagation rules for addition, shown below. The value is calculated by the Tool and is expressed as a relative uncertainty, based on the following equations:

$$\text{absolute uncertainty: } \Delta U_{total} = \sqrt{\Delta U_{ECM1}^2 + \Delta U_{ECM2}^2 + \Delta U_{ECM3}^2 + \text{and so on}}$$

$$\text{relative uncertainty: } U_{total} = \Delta U_{total} / SAV_{total}$$

*Total M&V Cost.* The sum of the M&V costs for each ECM. The Tool calculates this sum, using the following equation:

$$Cost_{total} = Cost_{ECM1} + Cost_{ECM2} + Cost_{ECM3} + \text{and so on}$$

*Project Report.* A report of each ECM included in the project. This report should be designed so that it includes, at a minimum, the following information for each ECM: ECM name and ECM category, M&V method description, project and ECM savings, project and ECM savings uncertainty, and project and ECM M&V cost.

**Table 2. Project Level Properties**

Property	Description	I/O Indication	Input/Output Options	Input/Output Option Notes
Project Name	Project name	User inputs data		
ECM Names	Names of each ECM included in project	Tool provides information	List of ECM names defined for this project name.	The user defines ECMs at the ECM level
Project Savings	Sum of savings from each ECM	Tool calculates value		
Project Savings Uncertainty	Combined uncertainty of all ECMs	Tool calculates value		
Total M&V Cost	Aggregated M&V cost for all ECMs	Tool calculates value		
Project Report	Summaries of ECMs that includes information on ECM type, M&V methods, savings, uncertainty, M&V cost, total project savings, and uncertainty and costs	Tool provides information		

### 4.3.3. ECM Level

Table 3 lists all properties in the ECM Level.

*ECM Name.* A name given to the ECM by the user. For example, “Pump SW-3 VFD,” or “Corporate Tower 300-ton Chiller Replacement,” and so on.

*Savings Type.* Energy savings, demand savings, or both energy and demand savings—the user may choose either or both of the two types. *Note: algorithms and descriptions of demand savings are not included in these specifications. They will be added at a later date.*

*Fuel Type.* Indicates whether the ECM equipment uses electricity or natural gas. The user may select one or the other, but not both. For ECMs that produce both electric and natural gas savings, such as boilers and furnaces, the user should create two separate ECMs.

*Energy Rate.* The cost per unit of energy consumed,  $\text{Rate}_E$ , as defined by the user.

*Demand Rate.* The charge per unit of energy demand,  $\text{Rate}_D$ , as defined by the user.

*ECM Category.* The type of ECM equipment. In these specifications, the user may choose from six categories: lighting, fan and pump motors, chillers, boilers, furnaces, and package AC units (air-conditioning only).

*Load Class.* Indicates whether the ECM equipment operates under constant-load or variable-load conditions—the user may choose one or the other. ASHRAE 14P defines constant-load equipment as equipment with loads that do not vary more than 5% while in operation. (The Tool allows the user to define this level of variation in the data collection equipment level.) Variable-load equipment are equipment with energy (or demand) consumption that is influenced by some independent variable.

*Schedule Class.* Indicates whether the ECM equipment operates under a timed schedule or a variable schedule. The user indicates the class by selecting from tool-provided options. Timed-schedule equipment operate at pre-set hours over the year. Variable-schedule equipment operate under the influence of some independent variable.

*Retrofit Change.* Indicates the retrofit’s impact on the load or schedule of the equipment. Six options from which the user may choose are included in these specifications:

- (1) load change, in which the retrofit serves to reduce the load on the equipment or improve the equipment efficiency
- (2) schedule change, in which the amount of time the equipment is in operation is reduced
- (3) load and schedule change, in which both the load and schedule are affected
- (4) constant load to variable load, in which the load is made dependent on the level of service required, generally reducing the load required for the task at hand

- (5) timed schedule to variable schedule, in which the schedule is made dependent on the level of service required, generally reducing the operation hours to complete the task at hand
- (6) constant load and timed schedule to variable load and variable schedule, in which the load and schedule are both made dependent on the level of service required

*Usage Group Number.* Defines how many usage groups are included in the ECM. Usage groups are primarily used for ECMs with multiple similar pieces of equipment, such as lighting fixtures or motors. Used when measurements are made on a sample of equipment pieces, usage groups are populations of pieces of equipment that have similar load or schedule characteristics.

*Usage Group Name.* The name of the usage group, as defined by the user.

*Usage Group Population.* The number of pieces of equipment included in the usage group, as defined by the user.

*ECM Savings.* The energy or demand savings value,  $SAV_{ECM}$ , calculated by the Tool based on the chosen M&V method equation.

*ECM Savings Uncertainty.* The relative uncertainty,  $U_{ECM}$ , in energy or demand savings; this value is calculated by the Tool, based on the error propagation algorithm developed for the chosen savings equation.

*Cost Summary Report.* An interim report that summarizes the ECM, M&V method and savings equation chosen, data collection method, and data collection equipment to be used in the M&V scenario. Designers should format the report so that it allows users to clearly see what M&V activities are chosen for the M&V scenario under consideration.

*Number of Labor Categories.* The number of different staff levels that may be assigned to specific activities in the project, as defined by the user.

*Labor Rates.* The hourly rates for the different staff levels assigned to the different activities in the project, as defined by the user.

*Labor Hours.* The estimated number of hours each assigned staff person will spend on a specific activity, as defined by the user. M&V activities may include specification and installation of monitoring instruments, data collection activities, data analysis, and reporting.

*Direct Costs.* The price of a specific good or service associated with M&V activities. The Tool supports four categories of such costs:

- (1) Costs for measurement and monitoring equipment, provided by the Tool. Purchase costs may be amortized over a user-specified number of projects.
- (2) Other equipment-related costs such as instrument calibration expenses, maintenance and upkeep, software updates, and so on. The user provides estimates of these costs.

- (3) Travel costs, which include auto, airfare, public transportation, lodging, and per diem expenses, if necessary. The user provides this information.
- (4) Miscellaneous costs, as provided by the user.

*M&V Cost.* The estimated cost of carrying out one year of M&V activities, calculated by the Tool and based on the following equation:

$$\text{Cost}_{\text{ECM}} = \sum_{\text{activity } i} \text{Labor Rate}_i \times \text{Hours}_i + \sum \text{Direct Costs}$$

*Benefit-Cost Ratio.* The difference in ECM savings uncertainty between one M&V plan and a base case plan divided by the difference in cost of the “more certain” M&V plan and the base case plan. Multiple M&V plans may be defined for the same ECM. The Tool calculates the benefit-cost ratio using the following equation:

$$\text{Ratio}_{\text{B/C}} = \frac{(U_{\text{plan\#1}} \times \text{SAV}_{\text{ECM}} \times \text{Rate}_E) - (U_{\text{base case plan}} \times \text{SAV}_{\text{ECM}} \times \text{Rate}_E)}{\text{Cost}_{\text{plan \#1}} - \text{Cost}_{\text{base case plan}}}$$

*Fractional M&V Cost.* The fractional M&V cost is the percentage of ECM cost savings that are used for M&V, calculated by the Tool and based on the following equation:

$$\text{Ratio}_{\text{M\&V}} = \frac{\text{Cost}_{\text{plan\#1}}}{\text{SAV}_{\text{ECM}} \times \text{Rate}_E}$$

*ECM Report.* A report that provides the details of the M&V scenario, specific to the ECM. It includes all properties defined at this level. The report should note which properties are defined or selected by the user and which are calculated by the Tool.

**Table 3. ECM Level Properties**

Property	Description	I/O Indication	Input/Output Options	Input/Output Option Notes
ECM Name	ECM name given to measure	User inputs data		
Savings Type	Type of energy savings	User selects input option (both may be selected)	Energy	Energy in kWh, therms (nat. gas.), Btu, etc.
			Demand	Demand in kW
Fuel Type	Type of fuel equipment uses	User selects input option (one or the other, not both)	Electricity	
			Natural gas	
Energy Rate	Cost per unit of energy consumed	User inputs data		
Demand Rate	Cost per demand unit	User inputs data		
ECM Category	Baseline end-use category of ECM	User selects input option	Lighting	Selections filter choices of M&V equations
			Fan and Pump Motors	
			Chiller	
			Boiler	
			Furnace	
			Package HVAC Units (AC only)	
Load class	Type of load, based on ASHRAE 14P	User selects input option	Constant load	User may define level of variation (uncertainty) in constant-load equipment
			Variable load	Load varies with some independent variable
Schedule class	Type of schedule, based on ASHRAE 14P	User selects input option	Timed schedule	Equipment operates according to some pre-set schedule
			Variable schedule	Equipment operation is influenced by some independent variable
Retrofit Change	Defines the retrofit's impact on the load or schedule of the equipment. The retrofit change provides a means to filter the savings equation choices	User selects input option	Load change	Reduces load on equipment or improves efficiency of equipment
			Schedule change	Reduces amount of time equipment is used
			Load and schedule change	Reduces load or improves efficiency and reduces amount of time equipment is used
			Constant load to variable load	Makes load dependent on level of service required, generally reduces load

Property	Description	I/O Indication	Input/Output Options	Input/Output Option Notes
			Timed schedule to variable schedule	Makes schedule dependent on level of service required, generally reduces hours of operation
			Constant load and timed schedule to variable load and timed schedule	Makes load and schedule dependent on level of service required
Usage Group Number	Number of usage groups. Most frequently used for lighting and motor ECMs.	User inputs data		
Usage Group Name	Name given to a group of devices that share similar characteristics (most often to be used for lighting and motors).	User inputs data		
Usage Group Population	Number of pieces of equipment in the usage group	User inputs data		
ECM Savings	Value of savings for ECM, determined by M&V method equation	Tool calculates value		
ECM Savings Uncertainty	Value of savings uncertainty for the ECM, determined by error propagation rules applied to the M&V method equation	Tool calculates value		
Cost Summary Report	Preliminary summary of M&V activities for user to estimate labor and materials costs. Report to provide a list of M&V activities, instruments to be used, instrument costs, relationships to develop, monitoring required, calibration procedures needed, etc., upon which user can base costs	Tool provides information		
Numer of Labor Categories	The number of labor categories assigned to the project. Multiple labor categories allow different staff to be assigned to specific M&V activities.	User inputs data		
Labor Rates	The hourly labor rates to charge for M&V activities	User inputs data	Labor rate 1	E.g. for personnel assigned to instrument specification and set-up, data analysis, reporting, etc.
			Labor rate 2	E.g. for field tech who monitoring equipment installation and data downloads
Labor Hours	The number of hours specified for M&V activities	User inputs data	Labor hours 1	Labor hours associated with labor rate 1
			Labor hours 2	Labor hours associated with labor rate 2

Property	Description	I/O Indication	Input/Output Options	Input/Output Option Notes
Direct Costs	Costs for monitoring equipment, travel, incidentals, etc.	Tool provides information	Monitoring equipment cost	Sum of all amortized measurement instrument costs
		User inputs data	Other equipment costs	Other costs related to use of measurement instruments—calibration, repair, parts, etc.
		User inputs data	Travel and lodging expenses	
		User inputs data	Miscellaneous costs	
M&V Cost	Cost to perform chosen M&V scenario	Tool calculates value		
Benefit-Cost Ratio	Reduction in uncertainty, expressed in dollars, of one M&V plan over a selected base case plan, divided by the increased cost of the new M&V plan. If B/C > 1, new M&V plan is "better"	Tool calculates value		
Fractional M&V Cost	The ratio of cost of the M&V activities to the annual energy savings of the ECM	Tool calculates value		
ECM Report	Report providing details of M&V scenario for this ECM. Includes ECM name, M&V method name, savings equation, variables, values, uncertainties, data collection methods, etc.	Tool provides information		

#### 4.3.4. M&V Method Level

Table 5 lists all properties in the M&V Method Level.

*M&V Scenario Name.* The name given by the user to the M&V scenario to be developed. Note that multiple M&V scenarios may be developed for the same ECM; the M&V scenario name is a means of identifying each scenario. Examples include: “80/20 Sampling,” “90/10 Sampling,” “kW – speed model,” “continuous kWh monitoring.”

*M&V Plan Flag.* Indicates whether the current M&V plan is the base case plan, to which all other M&V plans will be compared, or whether it is one of the plans used to compare against the base case plan. These specifications include two comparison plans; however, designers may include as many comparison plans as desired.

*Equation Options.* A set of equations that the Tool provides. The specific equations that appear are determined by what the user has selected for the ECM category, load class, schedule class, and retrofit change. These inputs act as a filter to determine the list of equations. Appendix A contains four tables for each combination of load and schedule class. Each table shows which equations are allowed for each ECM category and retrofit change.

For example, if a lighting project were chosen, with baseline equipment characterized as constant load and timed schedule, and the retrofit change reduces the load (such as replacing magnetic ballasts and T-12 tubes with electronic ballasts and T-8 tubes), a set of three equations appears. These equations are:

$$E_{save} = (kW_{base} - kW_{post})HRS_{post}$$

$$E_{save} = kW_{base} \times HRS - kWh_{post}$$

$$E_{save} = kWh_{base} - kWh_{post}$$

*Equation Selection.* The user indicates which of the equations provided by the Tool to use in the M&V plan.

*Number of Operation Stages.* The Tool treats variable-load or variable-schedule equipment as a series of operation stages. The number of operation stages is specified by the user. For constant-load or timed-schedule equipment, the user must enter 1. For variable-load or variable-schedule equipment, the user must enter a number greater than 1.

Equipment that is not constant load may have instead two or more load levels. Examples include a two-speed fan, lighting circuits with two out of four lamps on switchable circuits, or high efficiency package HVAC units that operate at high and low speeds. Equipment that is continuously variable in response to some variable may be treated with a series of operation stages. The Tool will allow the user to specify as many operation stages as needed.

For variable-load or variable-schedule equipment, a load frequency distribution must be specified. The number of operation stages will also specify the number of operation hour bins included in the analysis.

*Equation Variables.* The equation variables are determined by the savings equation the user has selected. The Tool generates the variable symbols based on a character recognition algorithm. (The user assigns values to these variables at the data collection method level. Variables are characterized by their value and uncertainty.) The Tool reserves memory for each variable, including variables with multiple operating scenarios. The list of variables that can be included in a savings equation are shown in Table 4.

**Table 4. Equation variables**

Constant Load or Timed Schedule	Variable Load or Variable Schedule*	Description
kW	kW <sub>i</sub>	electric kilowatt demand
kWh	kWh <sub>i</sub>	electric kilowatt-hour consumption
HRS	HRS <sub>i</sub>	hours of operation
Eff	Eff <sub>i</sub>	equipment efficiency
Q <sub>L</sub>	Q <sub>L,i</sub>	equipment load
Btuh	Btuh <sub>i</sub>	gas rate of consumption
therms	Therms <sub>i</sub>	gas consumption in therms

\* i indicates there are 2 or more operation stages

*Error Propagation Algorithm.* An algorithm that operates on the savings equation to determine a separate equation for calculating the energy savings uncertainty. The algorithm uses standard propagation of error rules to determine how uncertainties should be combined in an equation that has several multiplication, division, addition, and subtraction mathematical operators. The standard propagation of error rules are listed below in order of their implementation priority:

(1) exponential:

$$x = a^k; \Delta x = ka^{k-1}(\Delta a)$$

$$x = a^{1/k}; \Delta x = \frac{a^{1/k}}{ka}(\Delta a)$$

(2) multiplication or division:

$$x = ab \text{ (or } a/b); U_x = \frac{\Delta x}{x} = \left[ \left( \frac{\Delta a}{a} \right)^2 + \left( \frac{\Delta b}{b} \right)^2 \right]^{1/2}$$

(3) addition/subtraction:

$$x = a + b \text{ (or } a - b\text{); } \Delta x^2 = \Delta a^2 + \Delta b^2$$

For example, when the Tool detects a multiplication sign, it determines the relative uncertainty of the product of the two variables by determining the sum of squares of the two variables.

**Table 5. M&V Method Level Properties**

Property	Description	I/O Indication	Input/Output Options	Input/Output Option Notes
M&V Scenario Name	Name of current M&V scenario developed for the same ECM. For use in calculating benefit-cost ratios	User inputs data		
M&V plan flag	Flag to indicate whether current M&V plan is the base case M&V plan, or is a plan to be compared to the base case plan in the benefit-cost ratio calculation.	User selects input option	base case	base case M&V plan
			plan #1	Number of comparison plans not limited to one or two—the designer may add as many as desired
Equation Options	A set of equations based on selections of the baseline ECM category, load class, schedule class, and retrofit change. See equation filters for list of all possible equations in Appendix A.	Tool provides information	Options vary depending on user's previous selections	See Appendix A for complete list
Equation Selection	The equation selected from the above list	User selects input option	list provided above	
Number of Operation Stages	Number of different levels of equipment operation, for use with variable-load or variable-schedule equipment	User inputs data	1: constant load or timed schedule	define only one value
			> 1: variable load or schedule	With a variable-load or variable-speed (or both) project, the user needs to define the number of operating scenarios of the equipment. Can define up to 10 operating stages. Examples: <ul style="list-style-type: none"> <li>• Load variation: using fan kW vs. airflow model - load level i is kW at airflow<sub>i</sub>.</li> <li>• Load frequency distributions: HRS vs. motor speed bins, at speed i, obtain number of hours at that speed, HRS<sub>i</sub></li> </ul>
Equation Variables	Variables determined by the savings equation and generated by the tool based on a character recognition algorithm. The tool returns symbols for the user to know which variables need to be characterized (value and uncertainty). Variables are passed to the next level to be characterized with values and uncertainties. The tool must reserve memory for variables, including variables with multiple operation stages.	Tool provides information	The variables that are presented are determined by user's previous selections	Table 4 lists all possible variables

Property	Description	I/O Indication	Input/Output Options	Input/Output Option Notes
Error Propagation Algorithm	The equation used to calculate savings uncertainty.	Tool provides information		Defined in the Tool using a character recognition algorithm on the mathematical operators in the savings equation. Uses standard propagation of error techniques for addition and subtraction, multiplication and division, and exponents

#### 4.3.5. Data Collection Method Level

Table 6 lists all properties in the Data Collection Method Level.

*Equation Variable Name.* The symbol of the variable to be defined (e.g., kW, kWh, HRS). The Tool presents each variable.

*Variable Value.* The numerical quantity of the variable being defined. The user must input this information based on some knowledge of the equipment in question.

- For constant load equipment, the value is the value of the constant load.
- For variable-load or variable-schedule ECMs, multiple operation stages are defined. For variable load equipment, the variable values are the dependent variable values at each stage. For variable schedule equipment, or timed schedule with variable load equipment, the variable values are the number of operation hours at each stage.
- For projects in which a sample of devices will be measured, the variable value is the value for the population, and it is determined from the sample average multiplied by the usage group population.

*Independent Variable Name(s).* For variable load equipment, a model between the dependent and one or more independent variables will be made (however, most models use a single independent variable). Examples of independent variables include: air and water flow, pressure, supply and return temperature, and so on.

*Data Collection Method.* The method the user intends to use to quantify the current variable. The user may choose one of six methods, which are presented to the user by the Tool and which are based on the load and schedule class selections made by the user at the ECM level. Not all methods are available for every load and schedule class. (The first two columns in Table 7 show the allowable data collection methods for each load and schedule class.) The six methods from which the user may choose are described as follows.

- Stipulation. The variable value is obtained from knowledge of the equipment's load or schedule, based on prior measurements, knowledge of the equipment, or manufacturer's data. The stipulation method is allowed for constant-load equipment, timed-schedule equipment, or variable-schedule equipment.
- Single spot measurement. The variable value is obtained from a single spot measurement on the equipment. This method does not apply to variable-load or variable-schedule variables.
- Averaged spot measurements. The variable value is obtained from the average of a number of measurements on the equipment, using the same measurement instrument. This method also does not apply to variable-load or variable-schedule variables.
- Multiple spot measurements. A series of measurements of dependent and independent variables are made as the equipment is manually forced through its entire range of operation. The dependent variables are load variables such as kilowatts, equipment efficiency, or natural gas burn rate. Examples of independent variables are air or water flow rates, chilled or hot

water temperatures, and so on; their identity depends on the equipment and the proposed regression relationship. The measurements on the dependent and independent variables are used to develop a relationship between the load variable and an independent variable, usually with statistical regression techniques. This method applies to variable-load variables only.

- **Short-term monitoring.** Measurements of a load or schedule variable, or a load variable and a selected independent variable (or variables) are made at constant intervals over a short-term period. For measurements of constant-load projects, the period must be long enough to capture all variation in the load. For variable-load projects, the load variable and a selected independent variable (or variables, if more than one parameter is identified) are monitored over a period long enough to capture the entire range of variation in the variables.
- **Continuous monitoring.** Used for monitoring variable load or variable schedule variables, such as energy consumption (kWh or therms) or operating hours. The measurements are made at constant intervals continuously.

*Number of Samples Per Usage Group.* The number of devices to be monitored in lieu of the total population of devices. This variable is for use only when the usage group population is greater than one. Sample sizes are determined using the following equations:

$$n = \frac{n^*}{1 + \frac{n^*}{N}}, \text{ and } n^* = \frac{Z^2 CV^2}{p^2},$$

where  $n^*$  is the unadjusted sample size,  $n$  is the adjusted sample size,  $CV$  is the coefficient of variation,  $CL$  is the sample size confidence limit, and  $p$  is the precision level desired. The first equation is a correction to the sample size  $n$ , when the population size  $N$  is small.  $Z$  is the standard normal deviate for the given confidence level ( $Z = 1.645$  for 90% confidence, 1.282 for 80% confidence).

There are four input options from which the user may choose:

- No sampling. In this case, the sample size is the same as the population size, meaning measurements are made on every device in the population.
- $CV = 0.5, CL = 90\%, p = 10\%$
- $CV = 0.5, CL = 80\%, p = 20\%$
- $CV, CL,$  and  $p$  are user-defined. For this option, the user has a choice of confidence limits (and resulting  $Z$  values) from the following table:

<b>CL</b>	50%	68%	80%	90%	95%	98%
<b>Z</b>	0.6745	1.000	1.2816	1.6449	1.9600	2.5758

For the last three options, the uncertainty due to sampling is calculated with the following equation:

$$U_{\text{samp}}^2 = \frac{CV^2}{n} \left( 1 - \frac{n}{N} \right)$$

*Variable Total Uncertainty Value.* The combined variable and sampling uncertainty (the user defines variable uncertainty at the data collection equipment level). The Tool calculates this value using the following equation:

$$U_{\text{var,tot}}^2 = U_{\text{samp}}^2 + U_{\text{var}}^2$$

All uncertainties are specified at the 68% confidence level.

**Table 6. Data Collection Method Level Properties**

Property	Description	I/O Indication	Input/Output Options	Input/Output Option Notes
Equation Variable Name	Name of variable to be characterized, passed from previous level	Tool provides information	Load variable (kW, kWh, Eff, QL, Btuh, therms)	
			Schedule variable (HRS)	
Variable Value	Value of variable being defined—may be more than one value for a variable-load or variable-schedule project	User inputs data	Single value	User input (for a constant-load or timed-schedule value)
			Up to 10 values for each operation scenario	User input (for variable load or load frequency distribution)
Independent Variable Name	For variable load projects, the name of the independent variable to be measured along with the dependent variable and data used to construct the model.	User selects input option	Pressure, RH, Temp, Air Flow, Water Flow, and so on	Tool obtains list of names from the Equipment Table.
Data Collection Method	Method being used to quantify the current variable. Choices are filtered by load class and schedule class.	User selects input option	Stipulation	The variable value is estimated based on user knowledge of system or manufacturer data.
			Single spot measurement	The value is obtained from a single measurement of the variable
			Averaged spot measurements	The value is obtained from an average of multiple single measurements of the variable
			Multiple spot measurements	Several values are obtained from spot measurements taken while the load on the equipment is manually varied
			Short-term monitoring	Several values are obtained over time from measurements taken while the equipment operates and the load or schedule is allowed to vary naturally
			Continuous monitoring	Measurements are taken continuously while the equipment operates
Number of samples per usage group	For projects with a large number of devices in a usage group, sampling to reduce the number of measurement or monitoring points may be employed. Sample size n is based on the coefficient of variation about the mean, confidence level, and desired precision of the mean.	User selects input option	1	No sampling
			CV = 0.5, CL = 90%, p = 10%	Calculated sample size. Equations used: $n = n^*/(1+n^*/N)$ , $n^* = Z^2 CV^2 / p^2$ where $n^*$ is the unadjusted sample size, and n is the adjusted sample size for finite populations, Z is found from tabulated values based on the confidence level. $U_{\text{samp}}^2 = (CV^2/n)*(1 - n/N)$
			CV = 0.5, CL = 80%, p = 20%	
			User defined CV, CL and p	

Property	Description	I/O Indication	Input/Output Options	Input/Output Option Notes
Variable total uncertainty value	Total of all variable uncertainties (e.g., measurement, modeling and sampling) Expressed as a relative uncertainty value (in %), at 68% confidence level.	Tool calculates value		$U_{var,tot}^2 = U_{samp}^2 + U_{var}^2$

### 4.3.6. Data Collection Equipment Level

Table 8 lists all properties in the Data Collection Equipment Level.

*Equation Variable Name and Data Collection Method Name.* These properties were defined in previous levels and are repeated here as a reminder to the user when specifying the equipment and uncertainties used for collecting the variable data.

The allowable data collection methods are shown in Table 7 for the selected load and schedule classes. For each data collection method, Table 7 shows the relevant uncertainties that must be quantified.

*Relevant Uncertainties.* The relevant uncertainties are a set of uncertainties that make up the variable uncertainty property (defined below). Relevant uncertainties include uncertainties due to stipulation, measurement instruments, equipment load and schedule characteristics, and modeling techniques. Depending on the variable type, class, and data collection method, only a subset of these uncertainties will be relevant to the variable uncertainty. Each case is described below.

#### Constant Load

##### Stipulate

$U_{\text{stip}}$  is the uncertainty due to stipulating a variable quantity.

##### Single spot measurement

$U_{\text{inst,prec}}$  is the measurement instrument precision uncertainty.

$U_{\text{inst,bias}}$  is the measurement instrument bias uncertainty.

$U_{\text{eq,prec}}$  is the equipment precision uncertainty.

##### Averaged spot measurement

$U_{\text{inst,prec}}$  is the measurement instrument precision uncertainty.

$U_{\text{inst,bias}}$  is the measurement instrument bias uncertainty.

$U_{\text{eq,prec}}$  is the equipment precision uncertainty.

##### Short-term monitoring

$U_{\text{inst,prec}}$  is the measurement instrument precision uncertainty.

$U_{\text{inst,bias}}$  is the measurement instrument bias uncertainty.

$U_{\text{eq,prec}}$  is the equipment precision uncertainty.

#### Variable load

### Multiple spot measurements<sup>2</sup>

$U_{\text{meas,prec}}$  is the contribution of the independent variable's measurement precision uncertainty to the dependent variable's uncertainty.

$U_{\text{meas,bias}}$  is the contribution of the combined dependent and independent variable's measurement bias uncertainty to the dependent variable's uncertainty.

$U_{\text{model,prec}}$  is the model precision uncertainty.

$U_{\text{model,bias}}$  is the model bias uncertainty.

### Short-term monitoring<sup>3</sup>

$U_{\text{meas,prec}}$  is the contribution of the independent variable's measurement precision uncertainty to the dependent variable's uncertainty.

$U_{\text{meas,bias}}$  is the contribution of the combined dependent and independent variable's measurement bias uncertainty to the dependent variable's uncertainty.

$U_{\text{model,prec}}$  is the model precision uncertainty.

$U_{\text{model,bias}}$  is the model bias uncertainty.

### Continuous monitoring

$U_{\text{inst,prec}}$  is the measurement instrument precision uncertainty.

$U_{\text{inst,bias}}$  is the measurement instrument bias uncertainty.

### Timed Schedule

#### Stipulate

$U_{\text{stip}}$  is the uncertainty due to stipulating a variable quantity.

#### Short-term monitoring (for constant-load equipment)

$U_{\text{inst,prec}}$  is the measurement instrument precision uncertainty.

$U_{\text{inst,bias}}$  is the measurement instrument bias uncertainty.

$U_{\text{sched,bias}}$  is the schedule bias uncertainty.

#### Short-term monitoring (for variable-load equipment)

$U_{\text{inst,prec}}$  is the measurement instrument precision uncertainty.

$U_{\text{inst,bias}}$  is the measurement instrument bias uncertainty.

$U_{\text{bias,bin } i}$  is the schedule bias uncertainty of bin  $i$ .

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<sup>2</sup> The definitions of uncertainties for developing relationships between dependent and independent variables using measured variables are based on those in ASHRAE RP827.

<sup>3</sup> *Ibid.*

## Variable Schedule

### Stipulate

$U_{\text{stip}}$  is the uncertainty due to stipulating a variable quantity.

### Short-term monitoring

$U_{\text{inst,prec}}$  is the measurement instrument precision uncertainty.

$U_{\text{inst,bias}}$  is the measurement instrument bias uncertainty.

$U_{\text{bias,bin } i}$  is the schedule bias uncertainty of bin  $i$ .

### Continuous monitoring

$U_{\text{inst,prec}}$  is the measurement instrument precision uncertainty.

$U_{\text{inst,bias}}$  is the measurement instrument bias uncertainty.

*Relevant Uncertainty Values.* The relevant uncertainties (identified above) for the specific variable and data collection methods. The user must quantify these uncertainties in order for the Tool to determine the total variable uncertainty. The following rules are used to assist the user to quantify the uncertainties:

Stipulate. The stipulation uncertainty  $U_{\text{stip}}$  is estimated by the user; otherwise, a default value of 50% is assigned by the Tool.

Instrument precision and bias uncertainty. The measurement instrument precision and bias uncertainty ( $U_{\text{inst,prec}}$ ,  $U_{\text{inst,bias}}$ ) is obtained from the Equipment Table for the instrument selected by the user. The instrument precision and bias uncertainty specified in the Equipment Table are at the 68% confidence level.

Equipment precision uncertainty. This uncertainty is a property of the equipment load variation. It is an indication of how well the equipment can be classified as constant load equipment. ASHRAE 14P requires that this uncertainty be less than 5% in order to be considered constant load equipment.

For single spot measurements, the Tool assigns 5% to this uncertainty, because there is no means to verify it independently.

For averaged spot measurements and short-term monitoring, the user must estimate this quantity. However, the user should note that this quantity is the coefficient of variation of the series of measurements made on the equipment. When actual measurements are made, the data collected may be used to validate the user's assumption.

Independent variable measurement precision uncertainty contribution. For variable load equipment, in the development of a regression relationship between a load variable and one or more independent variables, this uncertainty,  $U_{\text{meas,prec}}$ , is the contribution of the

independent variable's instrument precision uncertainty to the overall dependent variable uncertainty. This definition follows the definitions provided in ASHRAE RP827 (1996). To determine it quantitatively, the model relationship must be known. Because the relationship may not be known prior to equipment testing, the user must estimate this uncertainty. ASHRAE RP827 provides some discussion in the magnitude of this uncertainty for models of chillers, pumps, and fans.

Combined dependent and independent variable measurement bias uncertainty contribution. For variable-load equipment, this uncertainty,  $U_{\text{meas,bias}}$ , is the contribution of the combined instrument bias uncertainties in the independent and dependent variables to the overall dependent variable uncertainty. This definition follows the definitions provided in ASHRAE RP827 (1996). To determine it quantitatively, the model relationship must be known. Because the relationship may not be known prior to equipment testing, the user must estimate this uncertainty. ASHRAE RP827 provides some discussion in the magnitude of this uncertainty for models of chillers, pumps, and fans.

Model precision uncertainty contribution. This uncertainty,  $U_{\text{model,prec}}$ , accounts for the validity of the regression model to fit the measured data, and also accounts for the measurement precision uncertainty of the dependent variable. This uncertainty is based on the standard error of the regression model used to model the relationship between the load and chosen independent variables. The user must estimate this uncertainty. ASHRAE RP827 provides some discussion in the magnitude of this uncertainty for models of chillers, pumps, and fans.

Model bias uncertainty. The model bias uncertainty,  $U_{\text{model,bias}}$ , is the uncertainty resulting from extrapolating the regression model beyond the range of data used to develop it. The user must estimate this uncertainty. The user may input zero if the data points used to develop the model were collected over the entire range of equipment operation. Otherwise, some knowledge of how the equipment reacts outside the range of collected data is necessary to predict this uncertainty.

Schedule bias uncertainty. The schedule bias uncertainty,  $U_{\text{sched,bias}}$ , is the uncertainty associated with extrapolating the operation hour measurements taken over a short-term period to annual values. The user must estimate this uncertainty.

Schedule bias uncertainty for bin i. The schedule bias uncertainty of bin i,  $U_{\text{bias,bin } i}$ , is the uncertainty associated with extrapolating operation hour measurements taken over a short-term period for each bin to annual values. The user must estimate each bin's schedule bias uncertainty.

*Measurement Instrument List.* A list of measurement instruments that may be used to quantify the load or schedule variable. The Tool develops this list from the Equipment Table, using the variable type and data collection method as filters so that only the relevant measurement equipment names are shown to the user. For example, if the variable is kW, the load class is constant, and the data collection method is "averaged spot measurements," then only hand held wattage measurement instrument names will be displayed.

*Selected Measurement Instrument.* This is the instrument name selected by the user. Selection of an instrument name includes all characteristics of the instrument, such as: instrument name, manufacturer, type, description, measurement class, equipment cost, precision and bias uncertainty, and amortization factor.

*Independent Variable Instrument.* For variable load projects, an independent variable must also be measured in order to develop models. The Tool develops a list of independent variable instrument names from the Equipment Table, filtering the list by the Independent Variable Name and the equipment designated as an “independent variable.” The user selects a name from the list. Examples of independent variables include: air flow measurement devices, water flow measurement devices, variables used as proxies (such as pressure for flow variables, current for wattage), air and water temperatures, and so on. Selection of an independent variable instrument name includes all characteristics of the instrument, including cost.

*Variable Uncertainty.* The variable uncertainty is the combined uncertainty of all relevant uncertainties identified by the variable type, class, and data collection method. The following equations are used to calculate the variable uncertainty in each category. Note that for two constant load cases, the user must define the number of measurements taken,  $n_p$ .

### Constant Load

#### Stipulate

$$U_{\text{var}} = U_{\text{stip}}$$

#### Single spot measurement

$$U_{\text{inst}} = (U_{\text{inst,prec}}^2 + U_{\text{inst,bias}}^2)^{1/2}$$

$$U_{\text{var}} = U_{\text{prec}} + U_{\text{inst}}$$

#### Averaged spot measurement

$$U_{\text{inst}} = (U_{\text{inst,prec}}^2 + U_{\text{inst,bias}}^2)^{1/2}$$

$$U_{\text{meas}} = 1/(n_p)^{1/2} \times \Delta U_{\text{inst}} / \text{VAR}_{\text{avg}}, \text{ VAR}_{\text{avg}} \text{ is the variable value defined previously}$$

$n_p$  = number of points, user defined

$$U_{\text{eqp,prec}} = \text{user defined (STDEV/VAR}_{\text{avg}}, \text{ the coefficient of variation)}$$

$$U_{\text{var}} = U_{\text{eqp,prec}} + U_{\text{meas}}$$

#### Short-term monitoring

$$U_{\text{inst}} = (U_{\text{inst,prec}}^2 + U_{\text{inst,bias}}^2)^{1/2}$$

$$U_{\text{meas}} = 1/(n_p)^{1/2} \times \Delta U_{\text{inst}} / \text{VAR}_{\text{avg}}, \text{ VAR}_{\text{avg}} \text{ is the variable value defined previously}$$

$n_p$  = number of points, user defined

$$U_{\text{eqp,prec}} = \text{user defined (STDEV/VAR}_{\text{avg}}, \text{ the coefficient of variation)}$$

$$U_{\text{var}} = U_{\text{eqp,prec}} + U_{\text{meas}}$$

Variable Load

## Multiple spot measurement

$$U_{\text{var}} = U_{\text{meas,prec}} + U_{\text{meas,bias}} + U_{\text{model,prec}} + U_{\text{model,bias}}$$

## Short-term monitoring

$$U_{\text{var}} = U_{\text{meas,prec}} + U_{\text{meas,bias}} + U_{\text{model,prec}} + U_{\text{model,bias}}$$

## Continuous monitoring

$$U_{\text{var}} = (U_{\text{inst,prec}}^2 + U_{\text{inst,bias}}^2)^{1/2}$$

Timed Schedule

## Stipulate

$$U_{\text{var}} = U_{\text{stip}}$$

## Short-term monitoring (for constant-load variable)

$$U_{\text{inst}} = (U_{\text{inst,prec}}^2 + U_{\text{inst,bias}}^2)^{1/2}$$

$$U_{\text{var}} = U_{\text{inst}} + U_{\text{sched,bias}}$$

## Short-term monitoring (for variable-load variable)

$$U_{\text{inst}} = (U_{\text{inst,prec}}^2 + U_{\text{inst,bias}}^2)^{1/2}$$

$$U_{\text{var, bin } i} = U_{\text{inst}} + U_{\text{bias, bin } i}$$

Variable Schedule

## Stipulate

$$U_{\text{var, bin } i} = U_{\text{stip, bin } i}$$

## Short-term monitoring

$$U_{\text{inst}} = (U_{\text{inst,prec}}^2 + U_{\text{inst,bias}}^2)^{1/2}$$

$$U_{\text{var, bin } i} = U_{\text{inst}} + U_{\text{bias, bin } i}$$

## Continuous monitoring

$$U_{\text{var, bin } i} = (U_{\text{inst,prec}}^2 + U_{\text{inst,bias}}^2)^{1/2}$$

*Amortization Factor.* A fraction, to be applied to the measurement equipment purchase cost. Users may not want to apply the entire equipment cost to one project, the amortization factor

allows users to include only a fraction of the cost to M&V plan cost. This is equivalent to spreading the cost over multiple M&V plans.

*Equipment Cost.* The cost of the required measurement equipment. This cost is the amortized purchase cost of the selected measurement instrument. When independent variables are also measured, their amortized purchase cost is also included. The Tool calculates the cost, using the following equation:

$$\text{Cost}_{\text{eqp}} = F_{\text{amort.inst}} \times \text{Cost}_{\text{inst.purchase}} + F_{\text{amort.ind.vav.}} \times \text{Cost}_{\text{ind.var.purchase}}$$

**Table 7. Relevant Uncertainties and Combination Rules filtered by Load and Schedule Class, and Data Collection Methods.**

Load and Schedule Class	Data Collection Methods	Relevant Uncertainties	Notes	Calculations
Constant load	Stipulate	$U_{stip}$	user estimates, or default = 50%	$U_{var} = U_{stip}$
	Single spot measurement	$U_{inst,prec.}$	from equipment table	$U_{inst} = (U_{inst,prec.}^2 + U_{inst,bias}^2)^{1/2}$
		$U_{inst,bias}$		
		$U_{eqp,prec.}$	= 5% (per 14P)	
Averaged spot measurements	$U_{inst,prec.}$	from equipment table, user inputs $n_p$	$U_{inst} = (U_{inst,prec.}^2 + U_{inst,bias}^2)^{1/2}$	
	$U_{inst,bias}$			$n_p$ = number of points $U_{meas} = 1/(n_p)^{1/2} \times \Delta U_{inst}/VAR_{avg}$
	$U_{eqp,prec.}$ (= CV(VAR) )	equipment variation	$U_{var} = U_{eqp,prec} + U_{meas}$	
Short-term monitoring	$U_{inst,prec.}$	from equipment table, user inputs $n_p$	$U_{inst} = (U_{inst,prec.}^2 + U_{inst,bias}^2)^{1/2}$	
	$U_{inst,bias}$			$n_p$ = number of points $U_{meas} = 1/(n_p)^{1/2} \times \Delta U_{inst}/VAR_{avg}$
	$U_{eqp,prec.}$ (= CV(VAR) )	equipment variation, user defined	$U_{var} = U_{eqp,prec} + U_{meas}$	
Variable load	Multiple spot measurement	$U_{meas,prec.}$	user estimates	
		$U_{meas,bias}$		
		$U_{model,prec.}$		
		$U_{model,bias}$		
	Short-term monitoring	$U_{meas,prec.}$	user estimates	$U_{var} = U_{meas,prec} + U_{meas,bias} + U_{model,prec} + U_{model,bias}$
		$U_{meas,bias}$		
		$U_{model,prec.}$		
$U_{model,bias}$				
Continuous monitoring	$U_{inst,prec.}$	from equipment table	$U_{inst} = (U_{inst,prec.}^2 + U_{inst,bias}^2)^{1/2}$	
	$U_{inst,bias}$			$U_{var} = U_{inst}$
Timed schedule	Stipulate	$U_{stip}$	user estimates, default = 50%	$U_{var} = U_{stip}$
	Short-term monitoring (for constant load)	$U_{inst,prec}$	from equipment table	$U_{inst} = (U_{inst,prec.}^2 + U_{inst,bias.}^2)^{1/2}$
		$U_{inst,bias}$		
		$U_{sched,bias}$	user estimates	
	Short-term monitoring (for variable load)	$U_{inst,prec}$	from equipment table	$U_{inst} = (U_{inst,prec.}^2 + U_{inst,bias.}^2)^{1/2}$
		$U_{inst,bias}$		
$U_{bias,bin i}$		user estimates		

**Table 8 (continued)**

Load and Schedule Class	Data Collection Methods	Relevant Uncertainties	Notes	Calculations
Variable schedule	Stipulate	$U_{stip,bin\ i}$	user estimates, default = 50%	$U_{var} = U_{stip,bin\ i}$
	Short-term monitoring	$U_{inst,prec}$	from equipment table	$U_{inst} = (U_{inst,prec}^2 + U_{inst,bias}^2)^{1/2}$
		$U_{inst,bias}$		$U_{var, bin\ i} = U_{inst} + U_{bias, bin\ i}$
		$U_{bias,bin\ i}$	user estimates	
Continuous monitoring	$U_{inst,prec}$	from equipment table	$U_{var, bin\ i} = (U_{inst,prec}^2 + U_{inst,bias}^2)^{1/2}$	
	$U_{inst,bias}$			

**Table 8. Data Collection Equipment Level Properties**

Property	Description	I/O Indication	Input/Output Options	Input/Output Option Notes
Equation Variable Name	Name of variable to be quantified	Tool provides information (passed from a previous level)	A symbol for a variable (the variable having been determined previously at the M&V Method level). Examples include KW, KWh, HRS, therms	Allows user to know what variable is to be quantified. The measurement instruments will use the variable name to show only instruments capable of measuring that quantity.
Data Collection Method	Name of proposed method to quantify variable value	Tool provides information (passed from a previous level)	A data collection method, such as stipulation, single spot measurement, averaged spot measurements, etc.	Allows user to know how the data will be collected. The following user inputs at this level will only show relevant data collection equipment for the variable type and load class and the data collection method.
Relevant Uncertainties	Uncertainties (in the form of variable names) due to stipulation, measurement instruments, equipment load and schedule characteristics, and modeling techniques.	Tool provides information	The subset of uncertainties that are relevant for the particular variable type, class, and data collection method. Will be some combination of the following variables: $U_{stip}$ , $U_{inst,prec}$ , $U_{inst,bias}$ , $U_{eq,prec}$ , $U_{meas,prec}$ , $U_{meas,bias}$ , $U_{model,prec}$ , $U_{model,bias}$ , $U_{sched,bias}$ , $U_{bias,bin i}$ , $U_{stip,bin i}$ .	Tool screens for the set of relevant uncertainties; the screen is based on the variable type, class, and data collection method.
Measurement Instrument List	A list of measurement instruments that may be used to quantify the load or schedule variable. The list is obtained from the Equipment Table, using the variable type and data collection method as filters.	Tool provides information		Each item in the list contains the entire record of information from the Equipment Table: instrument name, manufacturer, type, description, measurement class, equipment cost, precision and bias uncertainty, and amortization factor
Selected Measurement Instrument	The selected measurement instrument	User selects input option	A measurement instrument name, as described above.	
Independent Variable Name	For variable load projects, an independent variable must also be measured in order to develop models. The user selects a variable name from the list. The list is obtained from the Equipment Table, listing only equipment designated as "independent variable"	User selects input option	A list of "independent variables" developed from the Equipment Table	Examples include air flow measurement devices, water flow measurement devices, proxy flow variables (such as pressure), temperatures, and so on. Variables have the same pieces of information as the measurement instruments specified above.
Relevant Uncertainty Values	Values for each relevant uncertainty identified	User inputs data	$U_{stip}$	Estimated by user or default value assigned by Tool = 50%

Property	Description	I/O Indication	Input/Output Options	Input/Output Option Notes
		User selects input option	U <sub>inst,prec</sub> U <sub>inst,bias</sub>	Tool obtains uncertainty values based on user selection of measurement instrument
		User inputs data	U <sub>eqp,prec</sub>	5% for single spot measurement; otherwise estimated by user
		User inputs data	U <sub>meas,prec</sub>	Estimated by user; guidance for chillers, pumps, and fans provided in ASHRAE RP827 (1996)
		User inputs data	U <sub>meas,bias</sub>	Estimated by user; guidance for chillers, pumps, and fans provided in ASHRAE RP827 (1996)
		User inputs data	U <sub>model,prec</sub>	Estimated by user; guidance for chillers, pumps, and fans provided in ASHRAE RP827 (1996)
		User inputs data	U <sub>model,bias</sub>	Estimated by user; zero for extensive data sets
		User inputs data	U <sub>sched,bias</sub>	Estimated by user
		User inputs data	U <sub>bias, bin i</sub>	Estimated by user
		User inputs data	U <sub>stip,bin i</sub>	Estimated by user
Variable Uncertainty	The combination of all relevant uncertainty values. The combination calculation depends on the variable type and class and the data collection method. Equations are shown in Table 7.	Tool calculates value		
Amortization Factor	A fraction of the measurement equipment purchase cost to be charged to the project.	User inputs data	F <sub>amort,inst</sub>	
Equipment Cost	The amortized cost of all measurement equipment.	Tool calculates value		$Cost_{eqp} = F_{amort,inst} \times Cost_{inst,purchase} + F_{amort,ind.vav.} \times Cost_{ind,var.purchase}$

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## Appendix A. Equation Filter Tables

Tables A1 through A4 use the following nomenclature:

### ECM Codes

L = Lighting

M = Fans/Pumps

C = Chillers

G = Boilers/Furnaces

P = Packaged Units (AC only)

### Variables and Constants

kW – electric demand in kilowatts

HRS – hours of operation

Eff – equipment efficiency (unitless)

$Q_L$  – equipment load (expressed as a rate, in kilowatts or Btuh, depending on application)

kWh – electric energy use in kilowatt-hours

therms – natural gas use in therms

Btuh – British Thermal Units per hour

$c_t$  – conversion constant between Btu and therms:  $1.0 \times 10^{-5}$  therms/Btu

**Table A1. Constant Load, Timed Schedule**

ECM Category	Retrofit Changes	Equation
L, M, C, P	Changes load	$E_{save} = (kW_{base} - kW_{post})HRS_{post}$
C, G, P		$E_{save} = (Eff_{base} - Eff_{post})Q_{L_{post}} \times HRS_{post}$
G	$c_t$ converts to therms	$E_{save} = c_t (Btuh_{base} - Btuh_{post})HRS_{post}$
L, M, C, P		$E_{save} = kW_{base} \times HRS - kWh_{post}$
C, P		$E_{save} = Eff_{base} \times Q_{L_{post}} \times HRS - kWh_{post}$
G		$E_{save} = Eff_{base} \times Q_{L_{post}} \times HRS - therms_{post}$
G		$E_{save} = c_t Btuh_{base} HRS - therms_{post}$
L, M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$
L, M, C, P	Changes Schedule	$E_{save} = kW (HRS_{base} - HRS_{post})$
C, G, P		$E_{save} = Eff_{base} \times Q_{L_{post}} (HRS_{base} - HRS_{post})$
G		$E_{save} = c_t Btuh (HRS_{base} - HRS_{post})$
L, M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$
L, M, C, P	Changes Load and Schedule	$E_{save} = kW_{base} HRS_{base} - kW_{post} HRS_{post}$
G		$E_{save} = c_t (Btuh_{base} HRS_{base} - Btuh_{post} HRS_{post})$
		$E_{save} = (Eff_{base} \times HRS_{base} - Eff_{post} \times HRS_{post}) Q_{L_{post}}$
L, M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$

ECM Category	Retrofit Changes	Equation
M, C, P	Changes Load to VL $HRS = \sum_i HRS_i$	$E_{save} = kW_{base} HRS - \sum_i kW_{post,i} HRS_i$
C, G, P		$E_{save} = Eff_{base} Q_{L_{post}} HRS - \sum_i Eff_{post,i} Q_{L_{post,i}} HRS_i$
G		$E_{save} = Btuh_{base} HRS - \sum_i Btuh_{post,i} HRS_i$
M, C, P		$E_{save} = kW_{base} \times HRS - kWh_{post}$
C, P		$E_{save} = Eff_{base} \times Q_{L_{post}} \times HRS - kWh_{post}$
G		$E_{save} = c_t \times Eff_{base} \times Q_{L_{post}} \times HRS - therms_{post}$
M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$
L, M, C, P	Changes Schedule to VS $HRS_{base} \neq HRS_{post}$ $HRS_{post} = \sum_i HRS_{post,i}$	$E_{save} = kW_{base} HRS_{base} - kW_{base} \sum_i HRS_{post,i}$
C, G, P		$E_{save} = Eff_{base} Q_{L_{post}} HRS_{base} - Eff_{base} Q_{L_{post}} \sum_i HRS_{post,i}$
G		$E_{save} = c_t \left( Btuh_{base} HRS_{base} - Btuh_{base} \sum_i HRS_{post,i} \right)$
L, M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$
M, C, P	Changes load to VL, schedule to VS	$E_{save} = kW_{base} HRS_{base} - \sum_i kW_{post,i} HRS_{post,i}$
C, G, P		$E_{save} = Eff_{base} Q_{L_{base}} HRS_{base} - \sum_i Eff_{post,i} Q_{L_{post,i}} HRS_{post,i}$

ECM Category	Retrofit Changes	Equation
G		$E_{save} = c_i \left( Btuh_{base} HRS_{base} - \sum_i Btuh_{post,i} HRS_{post,i} \right)$
M, C, P		$E_{save} = kW_{base} \times HRS_{base} - kWh_{post}$
C, P		$E_{save} = Eff_{base} \times Q_{L_{post}} \times HRS_{base} - kWh_{post}$
G		$E_{save} = c_i Btuh_{base} HRS_{base} - therms_{post}$
M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$

**Table A2. Constant Load, Variable Schedule**

ECM Category	Retrofit Changes	Equation
L, M, C, P	Changes load	$E_{save} = (kW_{base} - kW_{post})HRS_{post}$
C, G, P	$HRS_{base,post} = \sum_i HRS_{post,i}$	$E_{save} = (Eff_{base} - Eff_{post})Q_{L,post} \times HRS_{post}$
G		$E_{save} = c_t (Btuh_{base} - Btuh_{post})HRS_{post}$
	$c_t$ converts to therms	
L, M, C, P		$E_{save} = kW_{base} \times HRS_{post} - kWh_{post}$
C, P		$E_{save} = Eff_{base} \times Q_{L,post} \times HRS_{post} - kWh_{post}$
G		$E_{save} = Eff_{base} \times Q_{L,post} \times HRS_{post} - therms_{post}$
G		$E_{save} = c_t Btuh_{base} HRS_{post} - therms_{post}$
L, M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$
L, M, C, P	Changes Schedule	$E_{save} = kW(HRS_{base} - HRS_{post})$
C, G, P	$HRS_{base} = \sum_i HRS_{base,i}$	$E_{save} = Eff \times Q_{L,post} (HRS_{base} - HRS_{post})$
G	$HRS_{post} = \sum_i HRS_{post,i}$	$E_{save} = c_t Btuh(HRS_{base} - HRS_{post})$
L, M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$
L, M, C, P	Changes Load and Schedule	$E_{save} = kW_{base} HRS_{base} - kW_{post} HRS_{post}$
	$HRS_{base} = \sum_i HRS_{base,i}$	
G	$HRS_{post} = \sum_i HRS_{post,i}$	$E_{save} = c_t (Btuh_{base} HRS_{base} - Btuh_{post} HRS_{post})$
C, G, P		$E_{save} = (Eff_{base} \times HRS_{base} - Eff_{post} \times HRS_{post}) Q_{L,post}$
L, M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$

ECM Category	Retrofit Changes	Equation
M, C, P	Changes Load to VL $HRS = \sum_i HRS_i$	$E_{save} = kW_{base} HRS - \sum_i kW_{post,i} HRS_i$
C, G, P		$E_{save} = Eff_{base} Q_{L_{post}} HRS - \sum_i Eff_{post,i} Q_{L_{post,i}} HRS_i$
G		$E_{save} = Btuh_{base} HRS - \sum_i Btuh_{post,i} HRS_i$
M, C, P		$E_{save} = kW_{base} \times HRS - kWh_{post}$ (same as above?)
C, P		$E_{save} = Eff_{base} \times Q_{L_{post}} \times HRS - kWh_{post}$ (meter $Q_{L_{post}}$ , $HRS_i$ – same as above?)
G		$E_{save} = c_t \times Eff_{base} \times Q_{L_{post}} \times HRS - therms_{post}$ (meter $Q_{L_{post}}$ , $HRS_i$ – same as above?)
M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$

**Table A3. Variable Load, Timed Schedule**

ECM Category	Retrofit Changes	Equation
M, C, P	Changes load	$E_{save} = \sum_i (kW_{base,i} - kW_{post,i}) HRS_{post,i}$
C, G, P		$E_{save} = \sum_i (Eff_{base,i} - Eff_{post,i}) Q_{L_{post,i}} \times HRS_{post,i}$
G	$c_t$ converts to therms	$E_{save} = c_t \sum_i (Btuh_{base,i} - Btuh_{post,i}) HRS_{post,i}$
M, C, P		$E_{save} = \sum_i kW_{base,i} HRS_i - kWh_{post}$
C, P		$E_{save} = \sum_i (Eff_{base,i} Q_{L_{post,i}} HRS_i) - kWh_{post}$
G		$E_{save} = \sum_i (Eff_{base,i} Q_{L_{post,i}} HRS_i) - therms_{post}$
G		$E_{save} = c_t \sum_i (Btuh_{base,i} HRS_i) - therms_{post}$
M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$
M, C, P	Changes Schedule	$E_{save} = \sum_i kW_i (HRS_{base,i} - HRS_{post,i})$
C, G, P		$E_{save} = \sum_i Eff_i Q_{L_i} (HRS_{base,i} - HRS_{post,i})$
G		$E_{save} = c_t \sum_i Btuh_i (HRS_{base,i} - HRS_{post,i})$
M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$
M, C, P	Changes Load and Schedule	$E_{save} = \sum_i (kW_{base,i} HRS_{base,i} - kW_{post,i} HRS_{post,i})$
G		$E_{save} = c_t \sum_i (Btuh_{base,i} HRS_{base,i} - Btuh_{post,i} HRS_{post,i})$
C, G, P		$E_{save} = (Eff_{base} \times HRS_{base} - Eff_{post} \times HRS_{post}) Q_{L_{post}}$
M, C, P		$E_{save} = kWh_{base} - kWh_{post}$

ECM Category	Retrofit Changes	Equation
G		$E_{save} = therms_{base} - therms_{post}$
M, C, P	Changes Schedule to VS $HRS_{base} \neq HRS_{post}$	$E_{save} = \sum_i kW_{base,i} HRS_{base,i} - \sum_i kW_{base,i} HRS_{post,i}$
C, G, P		$E_{save} = \sum_i Eff_{base,i} Q_{L_{post,i}} HRS_{base,i} - \sum_i Eff_{base,i} Q_{L_{post,i}} HRS_{po}$
G		$E_{save} = c_t \left( \sum_i Btuh_{base,i} HRS_{base,i} - \sum_i Btuh_{base,i} HRS_{post,i} \right)$
M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$

**Table A4. Variable Load, Variable Schedule**

ECM Category	Retrofit Changes	Equation
M, C, P	Changes load	$E_{save} = \sum_i (kW_{base,i} - kW_{post,i}) HRS_{post,i}$
C, G, P		$E_{save} = \sum_i (Eff_{base,i} - Eff_{post,i}) Q_{L_{post,i}} \times HRS_{post,i}$
G	$c_t$ converts to therms	$E_{save} = c_t \sum_i (Btuh_{base,i} - Btuh_{post,i}) HRS_{post,i}$
M, C, P		$E_{save} = \sum_i (kW_{base,i} HRS_{base,i} - kWh_{post,i})$
C, P		$E_{save} = \sum_i (Eff_{base,i} Q_{L_{post,i}} HRS_{base,i} - kWh_{post,i})$
G		$E_{save} = \sum_i (Eff_{base,i} Q_{L_{post,i}} HRS_{base,i} - therms_{post,i})$
G		$E_{save} = c_t \sum_i (Btuh_{base,i} HRS_{base,i} - therms_{post,i})$
M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$
M, C, P	Changes Schedule	$E_{save} = \sum_i kW_i (HRS_{base,i} - HRS_{post,i})$
C, G, P		$E_{save} = \sum_i Eff_{base,i} Q_{L_{post,i}} (HRS_{base,i} - HRS_{post,i})$
G		$E_{save} = c_t \sum_i Btuh_{base,i} (HRS_{base,i} - HRS_{post,i})$
M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$
M, C, P	Changes Load and Schedule	$E_{save} = \sum_i kW_{base,i} HRS_{base,i} - \sum_i kW_{post,i} HRS_{post,i}$
G		$E_{save} = c_t \left( \sum_i Btuh_{base,i} HRS_{base,i} - \sum_i Btuh_{post,i} HRS_{post,i} \right)$
C, G, P		$E_{save} = \sum_i Eff_{base,i} Q_{L_{post,i}} HRS_{base,i} - \sum_i Eff_{base,i} Q_{L_{post,i}} HRS_{po}$

<b>ECM Category</b>	<b>Retrofit Changes</b>	<b>Equation</b>
M, C, P		$E_{save} = kWh_{base} - kWh_{post}$
G		$E_{save} = therms_{base} - therms_{post}$

## Appendix B. Equipment Table

Table B1. Equipment Table

Variable Name	Indep. Var?	Instrument Class	Instrument Name (Mfgr./Model#)	Instrument Description	Other Variables	Equip. Cost	Prec.* Uncert.	Bias* Uncert.	Notes
Q <sub>L</sub>		2	Controlotron 1010EP	dedicated liquid thermal energy logger	flow, temp. diff.	\$4,000		1.5%	
Q <sub>L</sub>		3	Controlotron 1010EP	dedicated liquid thermal energy logger	flow, temp. diff.	\$4,000		1.5%	
Q <sub>L</sub>		1	Controlotron 1010EN	portable liquid thermal energy logger	flow, temp. diff.	\$5,000		1.5%	
Q <sub>L</sub>		2	Controlotron 1010EN	portable liquid thermal energy logger	flow, temp. diff.	\$5,000		1.5%	
kW		1	Fluke 39	portable single phase power meter	volts, amps, freq., PF.	\$1,095		1.0%	Software available
Temp		2	Onset Hobo Logger H08-001-02	portable indoor air temp. logger		\$59	1.8%	1%	
Temp		2	Onset Hobo Logger H08-002-02	portable external air temp. logger		\$65	1.8%	1%	
Temp	yes	2	Onset Hobo Logger H08-003-02	portable air RH/temp logger	RH	\$85		5%	
Amps	yes	2	Onset Hobo Logger H08-006-04	portable indoor 4-channel logger	HRS, air Temp/RH	\$85		2%	Software available: \$95
Temp	yes	2	Onset Hobo Logger H08-006-04	portable indoor 4-channel logger	RH, HRS, 2 ext. chan.	\$85	1.8%	1%	Software available: \$95
RH	yes	2	Onset Hobo Logger H08-006-04	portable indoor 4-channel logger	Temp, HRS, 2 ext. chan.	\$85		5%	Software available: \$95
HRS		2	Onset Hobo Logger H08-006-04	portable indoor 4-channel logger	Air Temp/RH, 2 ext. chan.	\$85			Software available: \$95
Amps	yes	2	Onset Hobo Logger H08-008-04	portable outdoor 4-channel logger	HRS, air Temp/RH	\$169		2%	Software available: \$95

Variable Name	Indep. Var?	Instrument Class	Instrument Name (Mfgr./Model#)	Instrument Description	Other Variables	Equip. Cost	Prec.* Uncert.	Bias* Uncert.	Notes
Temp	yes	2	Onset Hobo Logger H08-008-04	portable outdoor 4-channel logger	RH, HRS, 2 ext. chan.	\$169	1.8%	1%	Software available: \$95
RH	yes	2	Onset Hobo Logger H08-008-04	portable outdoor 4-channel logger	Temp, HRS, 2 ext. chan.	\$169		5%	Software available: \$95
HRS		2	Onset Hobo Logger H08-008-04	portable outdoor 4-channel logger	Air Temp/RH, 2 ext. chan.	\$169			Software available: \$95
Temp	yes	2	Onset Hobo TMC20-HA	20 ft sensor cable		\$30	1.0%	1.3%	Attaches to logger
Amp	yes	2	Onset Hobo CT-C	0-100 Amp split-core AC current sensor		\$80		2%	Attaches to logger
HRS		2	Onset Hobo Logger H06-001-02	portable on/off state logger		\$69			Uncertainty negligible: 1 min/wk
HRS		2	Onset Hobo Logger H06-002-02	portable on/off lighting logger		\$69			Uncertainty negligible: 1 min/wk
HRS		2	Onset Hobo Logger H06-003-02	portable magnetic on/off logger		\$69			Uncertainty negligible: 1 min/wk
Pressure	yes	2	Onset Hobo Logger HPA-0015	0 to 16 psia		\$249	0.5%		
HRS		2	PST Smart Logger TOU-L	portable on/off TOU lighting logger		\$186			Triggered by photocell, uncertainty negligible: 1 min/wk. Single-user software: \$195
HRS		2	PST Smart Logger RTC-L	portable on/off run-time lighting logger		\$99			Triggered by photocell, uncertainty negligible: 1 min/wk. Single-user software: \$195
HRS		2	PST Smart Logger TOU-M	portable on/off TOU motor logger		\$186			Triggered by magnetic field, uncertainty negligible: 1 min/wk. Single-user software: \$195
HRS		2	PST Smart Logger RTC-M	portable on/off run-time current logger		\$99			Triggered by magnetic field, uncertainty negligible: 1 min/wk. Single-user software: \$195
HRS		2	PST Smart Logger TOU-CT	portable on/off TOU current logger		\$250			Senses electric current, uncertainty negligible: 1 min/wk. Single-user software: \$195
HRS		2	PST Smart Logger RTC-CT	portable on/off run-time current logger		\$155			Senses electric current, uncertainty negligible: 1 min/wk. Single-user software: \$195
HRS		2	PST Ultralite 1T/3P, 2T/2P, 4C or 4P	Portable temp. current and pulse logger	Temp, Amps, Pulse	\$495			Logger resolution <1%, 2400B modem: \$155, split-core CTs \$80 - \$130, clamp-on CTs: \$160 - \$699

Variable Name	Indep. Var?	Instrument Class	Instrument Name (Mfgr./Model#)	Instrument Description	Other Variables	Equip. Cost	Prec.* Uncert.	Bias* Uncert.	Notes
Temp	Yes	2	PST Ultralite 1T/3P, 2T/2P, 4C or 4P	Portable temp. current and pulse logger	HRS, Amps, Pulse	\$495		0.5%	Logger resolution <1%, 2400B modem: \$155, Temp sensor \$25, resolution 0.5 °F
Pulse	Yes	2	PST Ultralite 1T/3P, 2T/2P, 4C or 4P	Portable temp. current and pulse logger	Temp, Amps, HRS	\$495			Logger resolution <1%, 2400B modem: \$155, up to 10 pulses per second
Amps	Yes	2	PST Ultralite 1T/3P, 2T/2P, 4C or 4P	Portable temp. current and pulse logger	Temp, Pulse, HRS	\$495			Logger resolution <1%, 2400B modem: \$155
kW		1	Tecpel DPM 035	1-phase power meter		\$499.00		1.0%	
RH	Yes	3	Veris Alta HX-485	networked temp and RH sensors	Temp	\$208.44		3%	
Temp	Yes	3	Veris Alta TX-485	networked temp and RH sensors	RH	\$208.44	1%		
Temp	Yes	2,3	Veris Alta TX Series	space temperature		\$110.23		0.75%	
RH	Yes	2,3	Veris Alta HD Series	duct mount humidity			2.6%		
RH	Yes	2,3	Veris Alta HW Series	wall mount humidity		\$215.63	1.0%		
Temp	Yes	2	Veris Enspector E7001	temperature logger		\$360.00		0.5%	Logger Software: \$104.18, serial cable, \$14.88
HRS		2	Veris Enspector E7002	run time logger		\$284.81		0%	Logger Software: \$104.18, serial cable, \$14.88, accurate to 1 min/wk
kW		2	Enspector Veris E7003	power logger	HRS, kWh	\$306.00		0.5%	Logger Software: \$104.18, serial cable, \$14.88
kWh		2	Enspector Veris E7003	power logger	HRS, kW	\$306.00		0.5%	Logger Software: \$104.18, serial cable, \$14.88
RPM	Yes	1	Monarch Pocket-Tach 6110-010	direct reading		\$195.00	0.01%		
RPM	Yes	2,3	Monarch ACT 6140-032	direct reading		\$550.00	0.00%		
HRS		3	ACME K667	Connected to EMS		\$210.00	0.04%		

\*Uncertainties reported in the Precision Uncertainty and Bias Uncertainty columns are taken from manufacturer's specification. Following ASHRAE Guideline 1 and ASME 19.1-1998, precision and bias uncertainties are assumed to be at the 95% confidence level, unless specifically noted by the manufacturer. To obtain uncertainties at the 68% confidence level as required by the Tool, multiply the uncertainty (both precision and bias) by the ratio: 1/1.96.

**Table B2. Instrument Class Description**

Instrument Class	Description
1	Instrument used for single, average, or multiple spot measurements – typically portable or hand-held
2	Instrument used for multiple spot measurements or short-term monitoring
3	Instrument used for short-term or continuous monitoring – typically instrumentation is dedicated to one piece of equipment

## Appendix C. Tool Functional Testing

This section provides specification of Tool inputs and expected outputs for a lighting and a motor project. The inputs and outputs are provided for Tool developers to use in checking that their software algorithms are in compliance with the specifications. The test criteria are set up in tables that reflect the Tool levels and properties. Each table represents one level, and includes all relevant properties in that level. Please note that at the Data Collection Method and Data Collection Equipment level, a table is used to describe each variable. In most tables, input as well as output data are provided, although output data would not normally be seen by the user until all inputs have been defined.

For each property, an input/output indication is specified. These are:

1. user input data,
2. tool calculates value,
3. user selects input option, and
4. tool provides information.

If options are available, they are filtered from previous choices made in the Tool.

Following are notes on the structure of the tables:

- Bold print indicates the selected option,
- Grey boxes indicate that the information is provided or determined by the Tool,
- Clear boxes indicate that user provides the information, or selects from a list of options,
- Cross-hatched boxes indicate the property is not relevant to the definition of the M&V plan,
- Reports are not provided in these examples, but are indicated to be provided by the Tool.

### Testing Criteria for Lighting

The example lighting project is a fictitious project at a school building. It is assumed that the whole building has the same fixture type. The building currently has switches to control the light fixtures on/off operation. The retrofit will include an increase in lighting fixture efficiency and the installation of occupancy sensors. This is a constant load, variable schedule project. The M&V plan used here is to monitor pre- and post-retrofit hours of operation and to use stipulated wattages for the fixtures, which are obtained from a standard wattage table. This particular M&V method will demonstrate how sampling, using manufacturer specifications, and extrapolating from short-term monitoring to annual energy use is described in the Tool.

### ECM Level

Property	I/O Indication	Input Option	User Input	Tool Output
ECM Name	User inputs data		Lighting Project: new ballasts and occupancy sensors	
Savings Type	User selects input option (both may be selected)	<b>Energy</b> Demand		
Fuel Type	User selects input option (one or the other, not both)	<b>Electricity</b> Natural gas		
Energy Rate	User inputs data		\$0.10/kWh	
Demand Rate	User inputs data			
ECM Category	User selects input option	<b>Lighting</b> Fan and Pump Motors Chiller Boiler Furnace Package HVAC Units (AC only)		
Load class	User selects input option	<b>Constant load</b> Variable load		
Schedule class	User selects input option	Timed schedule <b>Variable schedule</b>		
Retrofit Change	User selects input option	Load change Schedule change <b>Load and schedule change</b> Constant load to variable load Timed schedule to variable schedule Constant load and timed schedule to variable load and timed schedule		

Property	I/O Indication	Input Option	User Input	Tool Output
Number of Usage Groups	User inputs data		3	
Usage Group Name	User inputs data		Offices Restrooms Common Areas	
Usage Group Population	User inputs data		1200 (Offices) 26 (Restrooms) 258 (Common Areas)	
ECM Savings	Tool calculates value			234,427 kWh
ECM Savings Uncertainty	Tool calculates value			19%
Cost Summary Report	Tool provides information			
Number of Labor Categories	User inputs data		2	
Labor Rates	User inputs data	Labor rate 1 Labor rate 2	\$65/hr \$80/hr	
Labor Hours	User inputs data	Labor hours 1 Labor hours 2	80 40	
Direct Costs	Tool provides information	Monitoring equipment cost		\$2,680.29
	User inputs data	Other equipment costs	\$5.00	
	User inputs data	Travel and lodging expenses	\$200	
	User inputs data	Miscellaneous costs	\$175	
M&V Cost	Tool calculates value			\$11,460
Benefit-Cost Ratio	Tool calculates value			N/A
Fractional M&V Cost	Tool calculates value			49%
ECM Report	Tool provides information			

### M&V Method

Property	I/O Indication	Input Option	User Input	Tool Output
M&V Scenario Name	User inputs data		Monitoring base and post hours	
M&V plan flag	User selects input option	<b>Base case</b> plan #1 plan #1		
Equation Options	Tool provides information	$E_{save} = kW_{base} HRS_{base} - kW_{post} HRS_{post}$ $E_{save} = kWh_{base} - kWh_{post}$		
Equation Selection	User selects input option	$E_{save} = kW_{base} HRS_{base} - kW_{post} HRS_{post}$		
Number of Operation Stages	User inputs data	Base Case Post Installation	1 10	
Equation Variables	Tool provides information			$kW_{base}$ $HRS_{base}$ $kW_{post}$ $HRS_{post}$
Error Propagation Algorithm	Tool provides information			

### Data Collection Method - $kW_{base}$

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$kW_{base}$
Variable Value	User inputs data		0.123/fixture (Offices) 0.123/fixture (Restrooms) 0.123/fixture (Common Areas)	
Independent Variable Name	User selects input option	Pressure, RH, Temp, Air Flow, Water Flow, Pulse, and so on		
Data Collection Method	User selects input option	<b>Stipulation</b> Single spot measurement Averaged spot measurements		
Number of samples per usage group	User selects input option	1 CV = 0.5, CL = 90%, p = 10% CV = 0.5, CL = 80%, p = 20% User defined CV, CL and p		
Variable total uncertainty value	Tool calculates value			3.1%

Data Collection Equipment -  $kW_{base}$

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$kW_{base}$
Data Collection Method	Tool provides information			Stipulation
Relevant Uncertainties	Tool provides information			$U_{stip}$
Measurement Instrument List	Tool provides information			
Selected Measurement Instrument	User selects input option	A measurement instrument name, as described above.		
Independent Variable Instrument	User selects input option	A list of "independent variables" developed from the Equipment Table		
Relevant Uncertainty Values	User inputs data	(from wattage table)	6% (95% conf. level)	
Variable Uncertainty	Tool calculates value			3.06% (68% conf. level)
Equipment Purchase Cost	Tool calculates value			\$0
Amortization Factor	User inputs data			
Equipment Cost	Tool calculates value			\$0

Data Collection Method -  $HRS_{base}$

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$HRS_{base}$
Variable Value	User inputs data		3,840 hours (Offices) 4,650 hours (Restrooms) 4,200 hours (Common Areas)	
Independent Variable Name	User selects input option	Pressure, RH, Temp, Air Flow, Water Flow, Pulse, and so on		
Data Collection Method	User selects input option	Stipulation <b>Short-term monitoring</b>		
Number of samples per usage group	User selects input option	1 <b>CV = 0.5, CL = 90%, p = 10%</b>  CV = 0.5, CL = 80%, p = 20%  User defined CV, CL and p		
Variable total uncertainty value	Tool calculates value			5.7% (Offices) 9.9% (Restrooms) 6.2% (Common Areas)

Data Collection Equipment -  $HRS_{base}$

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$HRS_{base}$
Data Collection Method	Tool provides information			Stipulation
Relevant Uncertainties	Tool provides information			$U_{inst,prec}$ $U_{inst,bias}$ $U_{sched,bias}$
Measurement Instrument List	Tool provides information			HOBO – 4-channel logger HOBO –on/off lighting logger PST smart lighting logger
Selected Measurement Instrument	User selects input option	HOBO –on/off lighting logger		
Independent Variable Instrument	User selects input option			
Relevant Uncertainty Values	Tool provides information		0% (95% conf. level) 0% (95% conf. level) 5% (95% conf. level)	$U_{inst,prec}$ $U_{inst,bias}$ $U_{sched,bias}$
Variable Uncertainty	Tool calculates value			2.6% (68% conf. level)
Equipment Purchase Cost	Tool calculates value			\$69
Amortization Factor	User inputs data		10%	
Equipment Cost	Tool calculates value			\$6.90 (per point) \$ 941.20 (all points)

Data Collection Method –  $KW_{post}$

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$KW_{post}$
Variable Value	User inputs data		0.089/fixture (Offices) 0.089/fixture (Restrooms) 0.089/fixture (Common Areas)	
Independent Variable Name	User selects input option			
Data Collection Method	User selects input option	<b>Stipulation</b> Single spot measurement Averaged spot measurements		
Number of samples per usage group	User selects input option	1 CV = 0.5, CL = 90%, p = 10% CV = 0.5, CL = 80%, p = 20% User defined CV, CL and p		
Variable total uncertainty value	Tool calculates value			3.1%

Data Collection Equipment –  $kW_{post}$

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$KW_{post}$
Data Collection Method	Tool provides information			Stipulation
Relevant Uncertainties	Tool provides information			$U_{stip}$
Measurement Instrument List	Tool provides information			
Selected Measurement Instrument	User selects input option			
Independent Variable Instrument	User selects input option			
Relevant Uncertainty Values	User inputs data	(from wattage table)	6% (95% conf. level)	
Variable Uncertainty	Tool calculates value			3.06% (68% conf. level)
Equipment Purchase Cost	Tool calculates value			
Amortization Factor	User inputs data			
Equipment Cost	Tool calculates value			\$0

Data Collection Method –  $HRS_{post}$

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$HRS_{post}$
Variable Value	User inputs data		3,600 hours (Offices) 2,800 hours (Restrooms) 3,900 hours (Common Areas)	
Independent Variable Name	User selects input option	Pressure, RH, Temp, Air Flow, Water Flow, Pulse, and so on		
Data Collection Method	User selects input option	Stipulation Short-term monitoring <b>Continuous Monitoring</b>		
Number of samples per usage group	User selects input option	1 <b>CV = 0.5, CL = 90%, p = 10%</b> CV = 0.5, CL = 80%, p = 20% User defined CV, CL and p		
Variable total uncertainty value	Tool calculates value			5.1% (Offices) 9.6% (Restrooms) 5.6% (Common Areas)

Data Collection Equipment –  $HRS_{post}$

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$HRS_{post}$
Data Collection Method	Tool provides information			Stipulation
Relevant Uncertainties	Tool provides information			$U_{inst,prec}$ $U_{inst,bias}$
Measurement Instrument List	Tool provides information			ACME K667
Selected Measurement Instrument	User selects input option	ACME K667		
Independent Variable Instrument	User selects input option	A list of “independent variables” developed from the Equipment Table		
Relevant Uncertainty Values	Tool provides information		0% (95% conf. level) 0% (95% conf. level)	$U_{inst,prec}$ $U_{inst,bias}$
Variable Uncertainty	Tool calculates value			0% (68% conf. level)
Equipment Purchase Cost	Tool calculates value			\$210
Amortization Factor	User inputs data		10%	
Equipment Cost	Tool calculates value			\$21 (per point) \$1,739 (all points)

***Testing Criteria for a Fan Motor***

This example project involves the addition of a variable frequency drive to an existing 150 HP fan motor. The existing motor runs 8760 hours per year at a constant load. After retrofit, the motor will continue to run 8760 hours per year, but at load levels more appropriate to its operation. The retrofit will change the constant load, timed schedule equipment to variable load, variable schedule equipment. This example demonstrates how to specify a variable load and schedule project. Two M&V scenarios are included, so that a benefit-to-cost comparison between the two plans may be made. The base case M&V plan involves development of a model to characterize the motor load with an independent variable. The comparison M&V plan ("M&V plan #1) involves continuously monitoring the energy consumed by the motor. The benefit-to-cost ratio compares the alternate M&V plan with the base case M&V plan.

## Base Case M&V plan

### ECM Level

Property	I/O Indication	Input Option	User Input	Tool Output
ECM Name	User inputs data		Installation of a VFD on a fan motor	
Savings Type	User selects input option (both may be selected)	<b>Energy</b> Demand		
Fuel Type	User selects input option	<b>Electricity</b> Natural gas		
Energy Rate	User inputs data		\$0.10 (per kWh)	
Demand Rate	User inputs data			
ECM Category	User selects input option	Lighting <b>Fan and Pump Motors</b> Chiller Boiler Furnace Package HVAC Units		
Load class	User selects input option	<b>Constant load</b> Variable load		
Schedule class	User selects input option	<b>Timed schedule</b> Variable schedule		
Retrofit Change	User selects input option	Load change Schedule change Load and schedule change CL to VL TS to VS <b>CL and TS to VL and VS</b>		
Number of Usage Groups	User inputs data		1	
Usage Group Name	User inputs data			
Usage Group Population	User inputs data			
ECM Savings	Tool calculates value			166,367 kWh
ECM Savings Uncertainty	Tool calculates value			36%
Cost Summary Report	Tool provides information			

Property	I/O Indication	Input Option	User Input	Tool Output
Number of Labor Categories	User inputs data		2	
Labor Rates	User inputs data	Labor rate 1 Labor rate 2	\$65/hr – technician \$80/hr – M&V specialist	
Labor Hours	User inputs data	Labor hours 1 Labor hours 2	32 24	
Direct Costs	Tool provides information	Monitoring equipment cost		\$114.50
	User inputs data	Other equipment costs	\$12.50 – logger software	
	User inputs data	Travel and lodging expenses	\$100 – mileage, meals	
	User inputs data	Miscellaneous costs	\$0 miscellaneous	
M&V Cost	Tool calculates value			\$4,227.00
Benefit-Cost Ratio	Tool calculates value			
Fractional M&V Cost	Tool calculates value			25%
ECM Report	Tool provides information			

M&V Method

Property	I/O Indication	Input Option	User Input	Tool Output
M&V Scenario Name	User inputs data		Develop kW – pressure model	
M&V plan flag	User selects input option	<b>base case</b> plan #1 plan #1		
Equation Options	Tool provides information	$E_{save} = kW_{base} HRS_{base} - \sum_i kW_{post,i} HRS_{post,i}$ $E_{save} = kW_{base} \times HRS_{base} - kWh_{post}$ $E_{save} = kWh_{base} - kWh_{post}$		
Equation Selection	User selects input option	$E_{save} = kW_{base} HRS_{base} - \sum_i kW_{post,i} HRS_{post,i}$		
Number of Operation Stages	User inputs data	Base case Post installation	1 10	
Equation Variables	Tool provides information			$kW_{base}$ $HRS_{base}$ $kW_{post,i}$ $HRS_{post,i}$
Error Propagation Algorithm	Tool provides information			

Data Collection Method (for  $kW_{base}$ )

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$kW_{base}$
Variable Value	User inputs data		58.2 kW	
Independent Variable Name	User selects input option			
Data Collection Method	User selects input option	Stipulation <b>Single spot measurement</b> Averaged spot measurements Short-term monitoring		
Number of samples per usage group	User selects input option	1 CV = 0.5, CL = 90%, p = 10% CV = 0.5, CL = 80%, p = 20% User defined CV, CL and p		
Variable total uncertainty value	Tool calculates value			5.5%

Data Collection Equipment (for  $kW_{base}$ )

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$kW_{base}$
Data Collection Method	Tool provides information			Single spot measurement
Relevant Uncertainties	Tool provides information			$U_{inst,prec}$ $U_{inst,bias}$ $U_{eqp,prec}$
Measurement Instrument List	Tool provides information			Fluke 39 power meter Tecpel DPM 035 power meter
Selected Measurement Instrument	User selects input option	Fluke 39 power meter		
Independent Variable Instrument	User selects input option			
Relevant Uncertainty Values	Tool provides information		0.51% 0% 5%	$U_{inst,prec}$ $U_{inst,bias}$ $U_{eqp,prec}$
Variable Uncertainty	Tool calculates value			5.5%
Amortization Factor	User inputs data		10%	
Equipment Cost	Tool calculates value			\$59.00

Data Collection Method (for  $HRS_{base}$ )

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$HRS_{base}$
Variable Value	User inputs data		8760 (hours)	
Independent Variable Name	User selects input option			
Data Collection Method	User selects input option	<b>Stipulation</b> Short-term monitoring		
Number of samples per usage group	User selects input option	1 CV = 0.5, CL = 90%, p = 10%  CV = 0.5, CL = 80%, p = 20%  User defined CV, CL and p		
Variable total uncertainty value	Tool calculates value			10%

Data Collection Equipment (for  $HRS_{base}$ )

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$HRS_{base}$
Data Collection Method	Tool provides information			Stipulation
Relevant Uncertainties	Tool provides information			$U_{stip}$
Measurement Instrument List	Tool provides information			
Selected Measurement Instrument	User selects input option			
Independent Variable Instrument	User selects input option			
Relevant Uncertainty Values	User inputs data		10%	
Variable Uncertainty	Tool calculates value			10%
Amortization Factor	User inputs data			
Equipment Cost	Tool calculates value			\$0

Data Collection Method (for  $kW_{post,i}$ )

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$kW_{post,i}$
Variable Value	User inputs data (i = 10)		18.65 19.92 21.98 24.81 28.43 32.82 38 43.95 50.69 58.2	
Independent Variable Name	User selects input option	<b>Pressure</b> RH Temp Air Flow Water Flow Pulse other		
Data Collection Method	User selects input option	Multiple spot measurements <b>Short-term monitoring</b> Continuous monitoring		
Number of samples per usage group	User selects input option	1 CV = 0.5, CL = 90%, p = 10% CV = 0.5, CL = 80%, p = 20% User defined CV, CL and p		
Variable total uncertainty value	Tool calculates value			9.0%

Data Collection Equipment (for  $kW_{post,i}$ )

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$kW_{post,i}$
Data Collection Method	Tool provides information			Short-term monitoring
Relevant Uncertainties	Tool provides information			$U_{meas,prec.}$ $U_{meas,bias}$ $U_{model,prec.}$ $U_{model,bias}$
Measurement Instrument List	Tool provides information			PST Elite kW Logger Veris power logger
Selected Measurement Instrument	User selects input option	Veris Enspector E7003		
Independent Variable Instrument	User selects input option	Onset Hobo temp indoor Onset Hobo temp external Onset Hobo RH/temp <b>Onset Hobo air pressure</b> PST Ultralite temperature Veris TX series, temperature Veris HD series, RH Veris HW series, RH Veris Enspector temperature Monarch Pocket-Tach Monarch ACT, rpm		
Relevant Uncertainty Values	User inputs data	$U_{meas,prec}$ $U_{meas,bias}$ $U_{model,prec}$ $U_{model,bias}$	3% 3% 3% 0%	
Variable Uncertainty	Tool calculates value			9.0%
Amortization Factor	User inputs data		10%	
Equipment Cost	Tool calculates value			\$55.50

Data Collection Method (for  $HRS_{post,i}$ )

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$HRS_{post,i}$
Variable Value	User inputs data (i = 10)		100 50 150 425 785 1565 2250 1750 985 700	
Independent Variable Name	User selects input option	<b>Pressure</b> RH Temp Air Flow Water Flow Pulse other		
Data Collection Method	User selects input option	Stipulation <b>Short-term monitoring</b> Continuous monitoring		
Number of samples per usage group	User selects input option	1 CV = 0.5, CL = 90%, p = 10% CV = 0.5, CL = 80%, p = 20% User defined CV, CL and p		
Variable total uncertainty value	Tool calculates value			2.0%

Data Collection Equipment (for  $HRS_{post,i}$ )

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$HRS_{post}$
Data Collection Method	Tool provides information			Short-term monitoring
Relevant Uncertainties	Tool provides information			$U_{inst,prec}$ $U_{inst,bias}$ $U_{bias, bin i}$
Measurement Instrument List	Tool provides information			none HOBO magnetic on/off TOU logger HOBO magnetic run-time logger PST Smart logger
Selected Measurement Instrument	User selects input option	none		
Independent Variable Instrument	User selects input option	Onset Hobo temp indoor Onset Hobo temp external Onset Hobo RH/temp <b>Onset Hobo air pressure</b> PST Ultralite temperature Veris TX series, temperature Veris HD series, RH Veris HW series, RH Veris Enspector temperature Monarch Pocket-Tach Monarch ACT, rpm		
Relevant Uncertainty Values	Tool provides information		0%	$U_{inst,prec}$
	User inputs data	$U_{bias, bin i}$	2%	$U_{inst,bias}$
Variable Uncertainty	Tool calculates value			2.0%
Amortization Factor	User inputs data		10%	
Equipment Cost	Tool calculates value			\$31.80

## M&V Plan #1

### ECM Level

Property	I/O Indication	Input Option	User Input	Tool Output
ECM Name	User inputs data		Installation of a VFD on a fan motor	
Savings Type	User selects input option (both may be selected)	<b>Energy</b> Demand		
Fuel Type	User selects input option	<b>Electricity</b> Natural gas		
Energy Rate	User inputs data		\$0.10 (per kWh)	
Demand Rate	User inputs data			
ECM Category	User selects input option	Lighting <b>Fan and Pump Motors</b> Chiller Boiler Furnace Package HVAC Units		
Load class	User selects input option	<b>Constant load</b> Variable load		
Schedule class	User selects input option	<b>Timed schedule</b> Variable schedule		
Retrofit Change	User selects input option	Load change Schedule change Load and schedule change CL to VL TS to VS <b>CL and TS to VL and VS</b>		
Number of Usage Groups	User inputs data		1	
Usage Group Name	User inputs data			
Usage Group Population	User inputs data			
ECM Savings	Tool calculates value			
ECM Savings Uncertainty	Tool calculates value			

Property	I/O Indication	Input Option	User Input	Tool Output
Cost Summary Report	Tool provides information			
Number of Labor Categories	User inputs data		2	
Labor Rates	User inputs data	Labor rate 1 Labor rate 2	\$65/hr – technician \$80/hr – M&V specialist	
Labor Hours	User inputs data	Labor hours 1 Labor hours 2	40 24	
Direct Costs	Tool provides information	Monitoring equipment cost		\$247.50
	User inputs data	Other equipment costs	\$12.50 – logger software	
	User inputs data	Travel and lodging expenses	\$50 – mileage, meals	
	User inputs data	Miscellaneous costs	\$0 miscellaneous	
M&V Cost	Tool calculates value			\$4,830.00
Benefit-Cost Ratio	Tool calculates value			1.46
Fractional M&V Cost	Tool calculates value			29%
ECM Report	Tool provides information			

### M&V Method

Property	I/O Indication	Input Option	User Input	Tool Output
M&V Scenario Name	User inputs data		Continuous post-installation kWh monitoring	
M&V plan flag	User selects input option	base case <b>plan #1</b> plan #2		
Equation Options	Tool provides information	$E_{save} = kW_{base} HRS_{base} - \sum_i kW_{post,i} HRS_{post,i}$ $E_{save} = kW_{base} \times HRS_{base} - kWh_{post}$ $E_{save} = kWh_{base} - kWh_{post}$		
Equation Selection	User selects input option	$E_{save} = kWh_{base} - kWh_{post}$		
Number of Operation Stages	User inputs data	Base case Post installation	1 1	
Equation Variables	Tool provides information			$kWh_{base}$ $kWh_{post}$
Error Propagation Algorithm	Tool provides information			

Data Collection Method (for  $kWh_{base}$ )

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$kWh_{base}$
Variable Value	User inputs data		509,832 kWh	
Independent Variable Name	User selects input option			
Data Collection Method	User selects input option	<b>Stipulation</b> Short-term monitoring Continuous Monitoring		
Number of samples per usage group	User selects input option	1 CV = 0.5, CL = 90%, p = 10% CV = 0.5, CL = 80%, p = 20% User defined CV, CL and p		
Variable total uncertainty value	Tool calculates value			10%

Data Collection Equipment (for  $kWh_{base}$ )

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$kWh_{base}$
Data Collection Method	Tool provides information			Stipulation
Relevant Uncertainties	Tool provides information			$U_{stip}$
Measurement Instrument List	Tool provides information			
Selected Measurement Instrument	User selects input option			
Independent Variable Instrument	User selects input option			
Relevant Uncertainty Values	User inputs data		10%	
Variable Uncertainty	Tool calculates value			10%
Amortization Factor	User inputs data			
Equipment Cost	Tool calculates value			

Data Collection Method (for  $kWh_{post}$ )

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			$kWh_{post}$
Variable Value	User inputs data (i = 10)		343,465	
Independent Variable Name	User selects input option	Pressure RH Temp Air Flow Water Flow Pulse other		
Data Collection Method	User selects input option	Multiple spot measurements Short-term monitoring <b>Continuous monitoring</b>		
Number of samples per usage group	User selects input option	1 CV = 0.5, CL = 90%, p = 10% CV = 0.5, CL = 80%, p = 20% User defined CV, CL and p		
Variable total uncertainty value	Tool calculates value			

Data Collection Equipment (for kWh<sub>post</sub>)

Property	I/O Indication	Input Option	User Input	Tool Output
Equation Variable Name	Tool provides information			kWh <sub>post</sub>
Data Collection Method	Tool provides information			Continuous monitoring
Relevant Uncertainties	Tool provides information			U <sub>inst,prec.</sub> U <sub>inst,bias</sub>
Measurement Instrument List	Tool provides information			PST Ultralite Veris Enspector E7003
Selected Measurement Instrument	User selects input option	PST Ultralite		
Independent Variable Instrument	User selects input option			
Relevant Uncertainty Values	User inputs data		3% 3%	U <sub>inst,prec.</sub> U <sub>inst,bias</sub>
Variable Uncertainty	Tool calculates value			0.3%
Amortization Factor	User inputs data		50%	
Equipment Cost	Tool calculates value			\$247.50